Water injection and removal from the beamtube

Abstract: The document summarizes the results of calculations made in 2008 described in DCC T080330 on the dynamics of water adsorbed on the beamtube walls and the pumpout. The intent is to provide a guide on decisions of when to open gate valves between the beamtube and the instrument chambers and to estimate the severity of accidents.

Introduction: Excess pressure in the beamtube compromises the performance of the interferometers due to phase noise from forward scattering by the residual gas. The most troublesome gases are those with large dipole moments which also tend to adsorb on walls and take long times to pump out. The worst offenders are high mass hydrocarbons and water. After the beamtube bakeout, the pressure of 100 amu and larger hydrocarbons as well as for water was measured to be less than 10^{-12} torr.

The strain noise from gas by forward scattering is given by

$$h(f) = 4.8 \text{ x } 10^{-21} R\left(\frac{\text{gas}}{\text{Hydrogen}}\right)\sqrt{<P(\text{torr})>_{4km}} \propto \alpha\sqrt{\frac{\rho}{vwL}}$$

where R is the ratio of the polarizability, α, to the square root of the thermal velocity, v, for the gas being considered to that of molecular Hydrogen. <P(torr)> is the average pressure of the gas over the arm length L which is proportional to ρ, the number density of the gas. w is the optical beam Gaussian radius. R for water is 3.3. In the original LIGO design we set a goal that the phase noise from forward scattering be less than 1.5 x 10^{-25} strain/sqrt(Hz), the naïve quantum limit for a 1 ton test mass at 1kHz. This set the goal water pressure averaged over the 4 km arm length as 10^{-10} torr

Requirement Until the calculations made in T080330, the condition for injection of water into the beamtube was a maximum of 400 torr liters per end for the lifetime of the facility to avoid compromising the goal pressure. The new calculations established that water injected into the beamtube did pump out of the tubes albeit slowly. The desorption from the surface led to a 1/t dependence of the pressure and column density of water when pumped at a rate larger than the readsorption rate. The modeling led to a simple relation between the injected pressure P_{inj} and the length of time of the injection t_{inj} to the pressure P remaining after a time of pumping t_{pump} given by

$$<P_{inj}> t_{inj} = <P> t_{pump}$$

the averages are taken over the length of the tube. For example, suppose an air leak in the tube brings the average pressure to 10^{-6} torr for 1 day and then the leak is fixed. About 1% of this pressure is water. It will take about 100 days of pumping to bring the average pressure of water in the tube back to the goal of 10^{-10} torr.

The initial estimates for calculating the water injected into the beamtube from the ends assumed a uniform distribution of the water in the tube. The total amount of water injected was estimated as the product of the water pressure in the cryo trap times the geometric transmission of the trap multiplied by the beamtube exposure time. The transmission was estimated as the cross section of the trap multiplied by the ratio of radius to the length of the trap. The quantity comes out in torr liters and was inventoried at both sites.

The calculations in T080330 were more nuanced for estimating the injection of water into the beamtube from the ends. The new estimates included the water beaming and the pumping by the trap. The estimates showed that the adsorbed water had a peak at about 600 meters into the tube from the ends and that the average pressure after several free molecular diffusion times (typically hours) in the tube was related to the pressure in the trap by

$$<P_{inj}> = \left(\frac{3\pi^2 a}{4L_{pmax\ in\ tube}}\right)P_{cryotrap}$$

where a is the radius of the beamtube, $L_{pmax\ in\ tube}$, the location of the maxmum pressure from the injection in the tube, approximately 600 meters from the end. The factor in the brackets is 1/130. As an example, if the water pressure in the cryo trap is 3×10^{-8} torr for ½ year, it will take about 1.2 years to return to the goal pressure 10^{-10} torr.