Note on Electrostatics in the LIGO suspensions

R. Weiss, June 6, 1995

Summary: The note estimates bounds for fluctuating forces on suspended masses due to varying electric fields. The estimates indicate that uncontrolled electric fields could influence the low frequency noise budget in the initial interferometer. Several steps are recommended: 1) a measurement of surface charge and decay time on the dielectric coating of the mirrors be carried out to refine the estimates, 2) if the worst case estimates are validated by these measurements, to search for an electrolytic conducting thin film coating with low optical loss, 3) as a general practice to hide all dielectric surfaces from the test masses by conducting surfaces or if possible to overcoat them with conducting thin films.

Introduction: A known noise source in precision mechanical instruments such as gravimeters and torsion balances and low energy charged particle spectrometers are stray electric fields from stored charge on dielectrics and contact potential differences on conductors. The fields fluctuate due to thermally driven mechanisms such as charge diffusion on the insulators and changes of the work function of the conducting surfaces because of crystal face reorientations and adsorbed gas motions.

Field strengths and surface charge densities:

Conductors: Contact potential differences between metals are a few volts so that a system constructed of different metals electrically connected together will produce static fields of the magnitude of the contact potential difference divided by the physical separations. Electric fields 10^{-2} to 10^{-1} volts/cm are likely to occur in the LIGO test mass chambers and suspensions. Even in a system where are all the surfaces have nominally the same work function (such as the gold coating done in beta ray spectrometers) field strengths of 10^{-3} volts/cm are experienced due to crystal face variations at the surfaces and the polarization of adsorbed gas at the surface.

Insulators: There are multiple mechanisms that leave surface charge on insulators, most involve abrasion associated with mechanical contacting which leaves one polarity on the surface and the other on the removed material.[1] The charges are carried by both ions and "free" electrons. A well known source of dielectric charging in vacuum is via dust which is moved during pump out. (The gas flow itself is not expected to abraid surfaces.) In the suspensions planned for the LIGO, contacting the limit stops is certain to leave charge on the dielectric surface. The cleaning operations on the mirror surfaces are another source of charging and even though the surface eventually becomes neutralized by ions in the air or electrolytic ions in the solvents, these neutralizing charges hop from site to neighboring available site causing electric field fluctuations at the surface. Net surface charge densities on dielectrics measured in vacuum run between 10^{-4} to 1 esu/cm^2 [1,2,3,4,5] with extereme values (such as metal rubbing against insulator) limited by field emission at 10^3 esu/cm^2.[1] The surface charge induced by cosmic ray muons is expected to be negligible. In air the surface charge is limited by the breakdown of air at the dielectric surface which corresponds to surface fields of 3×10^4 volts/cm and maximum charge densities of 10^1 esu/cm^2. [1,2,3]

An often used technique to reduce surface charge on dielectrics in vacuum is to coat the surface with a slightly conducting ionic film such as stannous chloride for transparent surfaces such as windows and metallic coatings (with insulating traces if electrical insulation is required) for opaque surfaces. If neither of these strategies can be used, the final method is to "hide" the dielectric behind conductors or to attach conductors to the dielectric in such a fashion to terminate the fields. For example, in the case of the test masses to attach a conducting cylinder to the mirror long enough so that the fields generated by the charges on the dielectric mirror surface are terminated on the cylinder. Clearly not a preferred solution, if needed, since such an electrostatic shield could have low frequency normal modes, could increase the mechanical dissipation of the test mass and interfere with magnetic drivers.

Estimates of the fluctuating forces: The best that can be done without real measurements on the test masses is to give bounds to the noise. The reasoning given is no better than a dimensional argument. Assuming the fluctuations of the fields can be treated as a Markov process with a single correlation time, the fluctuating force power spectrum, $F^2(f)$, will be related to the average force, $< F >$, by

$$F^2(f) \approx \frac{2 < F^2 >}{\pi\tau_0(\frac{1}{\tau_0^2} + (2\pi f)^2)}$$

where τ_0 is the correlation time of the process and f the frequency at which the fluctuations are evaluated. In the most likely cases for either contact potential fluctuations and dielectric surface charge density fluctuations, the reciprocal of the correlation time will be small compared to the frequency and the fluctuating force power spectrum becomes

$$F^2(f) \approx \frac{2 < F^2 >}{\pi\tau_0(2\pi f)^2)}$$

The average electrostatic force on a dielectric surface charge layer, σ, due to images in surrounding conductors is

$$< F > = \frac{(\sigma\ A)^2}{4\ d^2} = \frac{E^2\ A}{16\pi^2}$$

where A is the area associated with the charge distribution and d is the distance to the nearest conductor.

References:

1. *Contact and Frictional Electrification* W. R. Harper, Oxford Press, 1967

2. *Electrostatics and its Applications* A. Moore, Wiley-Interscience, 1973

3. *Electrostatics* J. A. Cross, Hilger, 1987

4. *The Generation and Dissipation of Static Charge on Dielectrics in a Vacuum* D. K. Davies, in *Static Electrification Conference Proceedings* London, May 1967, Institute of Physics and Physical Society Conference Series # 4

5. *Measurement of Electrostatic Charges on Glass* G. A. Turner and M. Balasubramanian, in *Electrostatiche Aufladung* 40 Vortrage, Internationale Tagung 1973 der DECHEMA, Band 72, # 1370 - 1409, 1974