Unsolved issues with the charging of the test masses

R. Weiss, October 6, 2014

Unfortunately, we do not yet have a firm understanding of the mechanism of the charging. Here are the current pieces of the puzzle:

- We have good evidence that the fluctuations in the charge are due to the ion pumps as the fluctuations rarely occur when the ion pumps are closed off from the system.
- Not all ion pumps behave the same way nor does a specific ion pump always produce the same emission.
- The emission by the ion pumps is most likely neutral (from the Gamma Vacuum tests).
- The ion pumps in Advanced LIGO do not have a direct line of sight to the test masses favoring the hypothesis that the initial emission by the ion pumps are UV and soft x-ray photons which can scatter from the vacuum envelope and other components in the system.
- Direct measurements have established that removing the *first contact* films leaves the test mass with a negative surface charge density.
- The ETMY at LLO, whether measured by the optical lever technique (Aston LLO#14730) or by displacement in the interferometer (Evans and Martynov LLO#14853) has a positive surface charge.
- When the bias and control electrodes for ETMY at LLO were held at a large positive voltage for an hour the positive charge increased. While when the electrodes were held at a large negative voltage for an hour the charge remained constant. (**This is the significant inconsistency in the data**.)
- The ETMX at LLO has a low charge with a tendency to be positive as measured by the optical lever technique (Aston LLO#14691,#14633,#14513)
- The ETMY at LHO has both positive and negative charge depending on the quadrant while the ETMX at LHO has primarily negative charge. The data comes from a long series of observations made by Sorazu.
- The initial charge on ETMY at LHO was negative for all quadrants. After discharge by the external ionizer the charge measured on all quadrants was reduced. When the ion pumps were opened to the system the negative charge recovered.

The difference in surface charge polarity at LLO and LHO is part of the puzzle but even more so is the difference in induced changes of the charge at the two sites. At LHO it seems the negative charge is repopulated after discharge by electrons derived from photo emission on neighboring surfaces when the ion pump is restored to the system. At LLO a positive potential on the electrodes seems to cause electrons to leave the test mass, this would imply there are electrons on the back surface of the test mass being drawn to the recoil plate. Of course, it is possible to explain this too by assuming the back surface of the test mass had an initial negative charge and it is being removed to the electrodes, but it is all too adhoc.

To be sure that we do have a puzzle, I strongly encourage that we do some further measurements that will confirm the sign of the charge on the test mass at LLO. Propose several measurements:

1. Establish that when the readback in the control room says one is applying a positive bias there is indeed a positive voltage measured on the bias line at the output of the driver circuit.
2. Establish that the displacement of the test mass when positive potentials are applied to the bias line are indeed in the direction of a repulsive force between the test mass and the recoil mass (assuming that the charge on the ETMY test mass is positive).

Note: the rule established in earlier writings where a positive bias offset for the oscillating force to go to zero is associated with a positive charge on the test mass has once again been changed when using the proper formulation of the force due to a charge on the test mass. See the new force equation derived by Evans and Martynov below.

Evans and Martynov in their measurements of the charge on the ETMY test mass at LLO (Log entry 14853) found they had to reformulate the electrostatic force on the charged test mass to fit their data. Their relation, modified to make a force increasing the gap between the recoil mass and the test mass as positive (repulsive), is given by

$$F = -\alpha(V_{bias} - V_{control})^2 - \gamma(V_{bias} + V_{control})^2 + \beta(V_{bias} + V_{control})$$

The first term is the force on the dielectric due to the polarization and field gradient, it is an attractive force. The second is a new term due the field leaving the electrodes and terminating on a grounded conductor outside of the test mass assumed to be the ring heater. The force arises from the polarization of the dielectric and the gradient of this field. This too is an attractive force. The last term is due to the charge on the test mass. (I had the sign for the control field wrong in an earlier formulation).

The expression is still not a complete model for the force as the areas of the bias and control electrodes need to be included. It is however good enough to establish the sign of the charge and represent the general nature of the force.

Evans and Martynov used two different types of excitations to determine the constants in the equation. Method A applied V_{bias} as a DC voltage and $V_{control}$ as a sinusoidal voltage at 3Hz. They searched for a bias voltage which nulled the motion at 3 Hz. Method B held V_{bias} at zero while $V_{control}$ was the sum of the 3Hz voltage and a constant voltage V_0. They searched for V_0 which nulled the 3 Hz motion. After some algebra one gets for the null of the sinusoidal force the relations:

$$\beta = -2\alpha(1 - \frac{\gamma}{\alpha})V_{\mathrm{bias}} \qquad \text{Method A}$$

$$\beta = 2\alpha(1 + \frac{\gamma}{\alpha})V_0 \qquad \text{Method B}$$

The data gave $\frac{\gamma}{\alpha} \sim 0.3$ and $\beta > 0$. The charge was positive. The charge measured by the optical lever method a week before was also positive. (Note: that the sign error in the charge term I made, when corrected as in the above equation, causes the offset bias voltage for no deflection to be negative when the charge is positive.)