New Folder Name Displacement Noise

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SUBJECT Predicted displacement noise due to the electric noise in the orientation control system

Abstract

The displacement noise due to the electric noise in the current global control system was roughly predicted. At 300Hz the noise from some test masses are bigger than the current shot noise, but still a bit lower than the existing interferometer noise. At 1kHz this kind of noise is well below shot noise.

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Introduction

When applied to the coil actuator, the electric noise of the global control system will cause orientation fluctuations of the test masses. It will appear as noise in the interferometer output, coupling with the displacement between the beam axis and the mass center.

Review

When the beam axis deviates from the mass center by d vertically (horizontally), the tilt (rotation) fluctuations of the mass, $\delta\theta$, will cause mass displacement fluctuations, δx, measured by the interferometer as:

$$\delta x = d \bullet \delta\theta.$$

Prediction method

The angle fluctuations of the masses due to the electric noise of the global control system, $\delta\theta$, can be represented as:

$$\delta\theta = Nc \bullet Tcx \bullet Cx\theta,$$

where Nc is the electric noise applied to the coil, Tcx is the transfer function from the coil voltages to the xy-processor output, and $Cx\theta$ is the calibration of the global sensor, that is the angle change which can produce 1V change in the xy-processor output.

We calculated δx by measuring Nc, Tcx, and $Cx\theta$, and just guessing d as 0.5mm to save time. The result is shown in Table 1.

Some details

(1) Since measuring the exact Tcx in high frequencies is time-consuming, we extrapolated by assuming that the slope of it is kept to 80dB/dec up to 1kHz. This had already been verified for the tilt of the end mass of the primary cavity (Huey).

(2) In general the Tcx for rotation is much lower than for tilt because of the lower secondary resonance frequency for rotation as compared with tilt. (The secondary resonance frequency is the frequency above which the test mass cannot follow the motion of the upper mass any more.) And we had already observed that a strong mechanical coupling between rotation and tilt would contaminate the pure Tcx for rotation. More exactly speaking, as for Huey mass the voltages

applied to the rotation coil produced about 30% of the tilt motion which can be produced by the same voltages to the tilt coil. Therefore in the Table the case with 30% coupling is also shown in parenthesis.

(3) Although the xy-processor has two poles around 300Hz, we can neglect them by having a constant calibration C$x\theta$ instead.

(4) We neglected the inductance of the coil because we didn't measure it for all coils. As for Huey coil, the inductance becomes comparable with the resistance around 400Hz. The existence of the inductance will reduce the current and so reduce the noise.

(5) The calibration of the global sensor was done by inserting glass slides in the optical path (before the lens if any) with the mass under local control. The error bar was fairly large (±30%).

(6) The calibration for the rotation of both near mirrors has not been done. Supposing that the beam spot is not far from round, we adopted the tilt value for rotation.

Result

The displacement noises for some test masses (ex. Huey, Tilt) are larger than the current typical shot noise (10^{-18} m/rHz), but a bit smaller than typical existing interferometer noise (10^{-15} – 10^{-16} m/rHz) at 300 Hz. They are all smaller than the typical shot noise (3×10^{-18} m/rHz) at 1kHz.

Question

The predicted displacement noise for Huey mass is much larger than the others. This is because it doesn't have a capacitance termination at the coil, which the other masses have. The capacitance is useful to reduce the voltage noise which is produced by the OP-amplifier in the preceding stage, but the disadvantage is that the induced voltages at coils can cause currents at high frequencies with such capacitances. For example the mass can be dragged by the motion of the coil. We have not yet come to a conclusion as to whether the capacitance should be installed or not.

Table 1 The predicted displacement noise caused by the electric noise of the global control system.

Test Mass	@f (Hz)	Nc(V/rHz)	Tcx(V/V)	Cxθ(rad/V)	$\delta\theta$(rad/rHz)	δx(rad/rHz)
H(Tilt)	300	5.6E-7	6.3E-2	2.3E-6	8.0E-14	4.0E-17
	1k	5.6E-7	5.1E-4	2.3E-6	6.5E-16	3.3E-19
H(Rot.)	300	3.2E-6	2.0E-3 (1.9E-2)	1.9E-6 (2.3E-6)	1.2E-14 (1.4E-14)	6.0E-18 (7.0E-17)
	1k	1.0E-7	1.6E-5 (1.5E-4)	1.9E-6 (2.3E-6)	3.0E-18 (3.5E-17)	1.5E-21 (1.7E-20)
L(Tilt)	300	1.8E-7	1.3E-4	4.6E-6	1.1E-16	5.4E-20
	1k	3.2E-8	1.1E-6	4.6E-6	1.6E-19	8.1E-23
L(Rot.)	300	1.8E-8	6.9E-6 (3.9E-5)	7.9E-6 (4.6E-6)	9.8E-19 (3.2E-18)	4.9E-22 (1.6E-21)
	1k	7.9E-9	5.6E-8 (3.3E-7)	7.9E-6 (4.6E-6)	3.5E-21 (1.2E-20)	1.7E-24 (6.0E-24)
HN(Tilt)	300	5.6E-7	3.1E-4	2.3E-5	4.0E–15	2.0E-18
	1k	1.8E-8	2.5E-6	2.3E-5	1.0E-18	5.2E-22
HN(Rot.)	300	3.2E-7	1.8E-5 (9.3E-5)	2.3E-5 (2.3E-5)	1.3E-16 (6.8E-16)	6.6E-20 (3.4E-19)
	1k	1.8E-8	1.4E-7 (7.5E-7)	2.3E-5 (2.3E-5)	5.8E-20 (3.1E-19)	2.9E-23 (1.6E-22)
LN(Tilt)	300	1.0E-7	2.3E-4	4.8E-5	1.1E-15	5.5E-19
	1k	1.0E-8	1.9E-6	4.8E-5	9.1E-19	4.6E-22
LN(Rot.)	300	4.5E-8	3.2E-5 (6.9E-5)	4.8E-5 (4.8E-5)	6.9E-17 (1.5E-16)	3.5E-20 (7.5E-20)
	1k	1.0E-8	2.6E-7 (5.7E-7)	4.8E-5 (4.8E-5)	1.2E-19 (2.7E-19)	6.2E-23 (1.4E-22)