SUSPENSION CONTROLS PROTOTYPE TEST PLAN

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The following test plan details the tests required to qualify the suspension controls prototypes as part of the suspension preliminary design. The tests are designed to reduce risk as the designs move forward into the final design phase. They are also designed to provide results that will be used to determine if the designs meet the controls prototype requirements.

There are 3 controls prototypes: 2 mode cleaner (MC) triple pendulum suspensions and 1 end test mass (ETM) quadruple pendulum suspensions. One MC is scheduled to be a bench prototype and remain at CIT. The other two (a MC and an ETM) will go to LASTI for final testing with LASTI chambers and Advanced LIGO seismic equipment. All controls prototypes at both sites will utilize dSPACE controllers for local control and monitoring. Testing that requires LASTI-based equipment is designated as such below. Other tests may be performed at either location. It has been proposed that one of the MCs could go to Stanford for testing in conjunction with the ETF active platform prototype – this is currently under discussion.

Key Tests

1. **Mechanical fit test.**

The mechanical fit test is meant to make sure that all mechanisms work, all parts fit together and no fabrication errors or drawing errors exist. It will be confirmed that the dummy optic can be positioned and oriented according to the requirements. Requirements detailed in the Design Requirements Documents, LIGO-T000053 and LIGO-T010007.

2. **Structure frequency measurements**

A piezo, impact hammer or another mechanical means will be used to induce vibration in the clamped-down structure. The mass to which the structure is clamped shall be much more massive than the suspension assembly and mechanically as stiff and non-lossy as possible. A large milling machine bed is ideal – an optical table is not suitable. An optical table may give frequencies that are lower than the final configuration. All non-suspended parts shall be assembled onto the structure. The suspended items should be included, if feasible. About as many clamps should be used as will be used in production. Low mass accelerometers with strain relieved cables will be used to identify at least the lowest-order longitudinal and transverse leaning modes and the lowest-order torsional mode of the structure, as well as any other low frequency modes that violate the minimum frequency requirement (150 Hz or TBD). Comparisons will be made with the finite-element model of the structure produced by the CAD software. If time permits, structural frequency tests should be performed at CIT and LASTI.

3. **Functional electronics test.**

This test is a stand-alone test of the analog electronics, digital electronics and the dSpace system along with all cabling. A single spare OSEM suffices for this test.

4. **Pendulum frequency measurements**

The OSEMs will be used to measure the pendulum frequencies of the suspension. A step input of order 10 mN in x, y, z and 0.5 mN·m in yaw, 0.1 mN·m in pitch and 1 mN·m in roll will be applied via the OSEMs at the top mass with the local servo off, to excite as many low frequency modes as possible. All of these numerical values are rough recommendations based on what was found was good for a triple pendulum suspension. They excite the pendulum to give displacements at the OSEMs that are a significant fraction of the linear range of the shadow sensors. The values are as suggested for the triple and TBD for the quad. The output of the top mass OSEMs, and, if available, any OSEMs on lower masses, will be logged for approximately 5 minutes and FFTed to produce mode shapes and frequencies. Comparison will be made with the Matlab/Simulink design model of the pendulum as well as the Mathematica model.

5. Damping test

The OSEMs will be used to measure the damping response of the pendulum under local control. A step input of order 10 mN in x, y, z, 0.5 mN.m in yaw, 0.1 mN.m in pitch and 1 mN.m in roll will be applied via the OSEMs at the top mass with the local servo on, to excite as many low frequency modes as possible. The output of the top mass OSEMs, and, if available, any OSEMs on lower masses, will be logged for approximately 1 minute and plotted to check that all modes are dying away as expected according to the Matlab/Simulink model of the pendulum and local control system, and in compliance with the 10 s (or TBD) or less requirement.

As before, these step inputs are rough recommendations for a triple pendulum suspension, although they will probably be about right for the quad as well. For the test with damping off, we're trying to get good resolution of the mode frequencies, so we want to sample for many periods. 300 s should give roughly 1% accuracy for modes around 0.3 Hz. For the test with damping on, if there are any modes still ringing significantly after 1 minute there is something wrong in the design of the controller or dampers and debugging needs to commence.

6. Installation test

An installation test will be performed with the controls prototypes, prototype or reworked LIGO 1 installation equipment and a HAM or BSC chamber (whichever is applicable, of course.) The optical table (the interface of the SEI and the SUS system) shall be at the Advanced LIGO height. It will be confirmed that the suspension can be moved securely from the assembly space at LASTI, into the chamber area and onto the table, without disturbing the positioning or orientation of the optic relative to the structure. Micropositioning of the structure along with final alignment techniques will be practiced. This test needs to be performed at LASTI.

7. **Eddy Current Damping Test**

Install eddy current damping (ECD) units and investigate ease of alignment. Measure level of damping on vertical and roll modes and compare to expected damping from MATLAB model.

SUSPENSION CONTROLS PROTOTYPE TEST PLAN

8. SEI & SUS testing, in vacuum

If a chamber used for the test has a rigid spacer with a HEPI, the HEPI will be used as a 6 DOF shaker table from DC to 20 Hz to measure selected transfer functions – the suspension sensors (‘OSEMS’) will be used to monitor mirror motion. In particular, since a HEPI can provide clean vertical excitation, vertical to horizontal coupling will be characterized. Also, a horizontal signal will be inserted and measurement of the horizontal to tilt coupling will be made. LASTI will provide in-vacuum geophones, and optical levers as needed. Mirror displacements may be independently monitored via low-sensitivity interferometry. Care should be taken to include about as many clamps to secure the SUS to the SEI optical table as will be used in production.

If the chamber has a stiff system installed, along with a HEPI, the tests detailed above will be done along with transfer function measurements between the floor (seismic), the stiff SEI system and the suspension shall be made. These measurements will be compared to the SEI and SUS models. The behavior may be compared with a forthcoming model.