Earthquake and other stops in the ETM/ITM design

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1 Introduction

In initial LIGO the earthquake stops served more than one purpose and in early discussion of advanced LIGO it was anticipated that they would also be used during ribbon welding as part of the "mass catcher" assembly. As the requirements have become clearer and design has progressed, it has been decided to use several different stops. There are already several documents about the earthquake and other stops; this one attempts to tie the whole picture together.

The other documents which should be consulted for fuller details are

G030376-00.pdf	useful history of earthquake stops on initial LIGO
E040457-00-K	requirements document
T060143-00-K	Mass position adjustment (the "pads")
T060144-00-K	Earthquake stops in the lower structure
T060053-00-K	Earthquake stop calculations
T060098-00-K	Earthquake stop calculations part 2
T060118-00-K	the PDS for the lower structure, shows FEA plots of stresses in the structure during an earthquake
T050190-00-K	The PDS for the tablecloth which includes information on the stops for the tops mass built in to the OSEM/ECD units. (section 4.3)

Issues which are dealt with primarily in the current document are

- A summary of the different stops and their uses
- Possible designs of the compliant earthquake stops for the non-metal masses

2 Uses of the different stops

2.1 Materials

In the list below we refer to stops of three materials. Metal stops are used in contact with metal masses. For non-metal masses we need

- a soft polymer for use during an earthquake. For charging reasons we will need to make silica tips for these stops
- a hard polymer for use to position the masses during assembly
- a hard polymer to use when the assembly is being moved. We do not want to rub the silica tips against the masses during such movement.

For the soft polymer we propose to use the vacuum-qualified grade of Flourel (as is used on the SEI system). For the hard polymer, which will contact the masses but won't be put into the vacuum system, we will use either PFA440 or a substitute such as PEEK.

2.2 Usage scenarios

We distinguish three scenarios in the table below. “During build” and “In operation” are largely self explanatory “In operation” includes protection against earthquake and against ribbon or wire breakage. “For moving” refers to the movements of partially-assembled suspensions that will be required during assembly and installation. Primarily these are

- Moving half of the lower chain from the assembly area to the ribbon welding area
- Moving the same half lower chain back again with the ribbons in place
- Moving the lower structure to the upper structure for integration
- Moving the lower and upper structures (separate or as a cartridge) into the vacuum tank. For this final move we are not yet decided whether to use the hard polymer stops (which would have to be removed in the tank) or the silica tipped stops (which might scratch the non-metal masses).

We are not currently planning to ship the suspension with masses installed.

Top mass	During build	Initially: Four vertical metal stops below the mass. Used to set height during early build.
		As the tablecloth is completed, four additional stops above the mass
		As the OSEM/ECD units are added, the complement of stops are completed (the stops are built into the OSEM/ECD units for ease of alignment).
	For moving	The four stops above and below the mass can the screwed down hard to hold the mass.
	In operation	All-metal stops on the OSEM/ECD units and the stops above and below.
UI mass	During build	Stops will be added progressively as required.
	For moving	All the stops are adjustable and can be screwed down hard to hold the mass
	In operation	The total count of adjustable metal stops is Four below the mass Two above (they in fact reach through the mass and are fixed below it) Two each end of the mass Two in front of the mass and two behind it
Pen Re mass (metal)	During build	PFA440 pads give nominal location and allow easy rotation “clocking” of the mass Silica-tipped Flourel stops will be fitted between the Pen Re mass and the PU mass but will not be used at this stage.
	For moving	PFA440 pads are left in place below the mass and metal stops inserted above, in front and behind. If both chains are moved together, PFA440 temporary stops will be inserted between the Pen Re mass and the PU mass, which are slightly longer than the Flourel stops.
	In operation	Metal stops are used around the periphery and on the “open” face. The metal stops below the mass can be inserted as the pads are removed so that at no stage is

		the mass unsupported. On the face that faces the penultimate mass, silica-tipped Flourel stops will be used
Penultimate (PU) mass	During build	PFA440 pads give nominal location and allow easy rotation “clocking” of the mass. Silica-tipped Flourel stops will be fitted between the Pen Re mass and the PU mass but will not be used at this stage.
	For moving	PFA440 pads are left in place below the mass and PFA440 screws inserted above, in front and behind. If both chains are moved together, PFA440 temporary stops will be inserted between the Pen Re mass and the PU mass, which are slightly longer than the Flourel stops.
	In operation	Silica-tipped Flourel stops will be fitted – this can be done as the PFA pads are removed so that at no stage is the mass unsupported. The total count is Eight around the barrel of the mass Four on the front face Four on the back face fixed to the PU reaction mass
Test mass	During build	PFA 440 pads with interchangeable parts allow the mass to be set in any of four locations: Nominal +9mm (for fibre welding) Nominal +8mm (for fibre equalisation) Nominal Nominal -2mm (for fibre stretch test) The mass will also be held by a jack below and the lever-arm clamp above. The jack is screw adjusted and cannot be moved abruptly. The lever-arm clamp allows the mass to be pushed down in a controlled manner for the overload test. Silica-tipped Flourel stops will be fitted between the Test mass and the reaction mass but will not be used at this stage.
	For moving	Below the test mass, the +8mm PFA pads will be used so that there is no tension in the ribbons. PFA stops will be added in front, on top of and behind the mass all of which can be done before the jack and lever-arm clamp are removed. If both chains are moved together, PFA440 temporary stops will be inserted between the test mass and the reaction mass, which are slightly longer than the Flourel stops.
	In operation	Silica-tipped Flourel stops will be fitted. The mass will be supported on the jack while the stops are swapped so that at no stage is the mass unsupported. The total count is Eight around the barrel of the mass Four on the front face Four on the back face fixed to the reaction mass

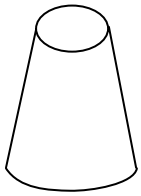
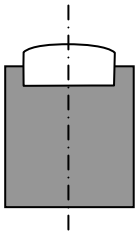
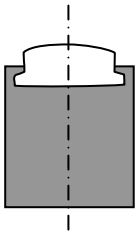
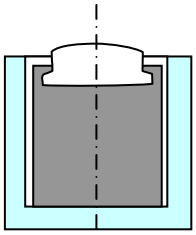
Reaction mass	During build	PFA440 pads will be used in conjunction with the tests-mass jack and lever arm clamp. They will be settable to predefined heights as required for the build. Silica-tipped Flourel stops will be fitted between the Test mass and the reaction mass but will not be used at this stage.
	For moving	PFA 440 pads will be used below, with PFA440 screws above, in front and behind, all of which can be added before the jack and lever-arm clamp are removed. If both chains are moved together, PFA440 temporary stops will be inserted between the test mass and the reaction mass, which are slightly longer than the Flourel stops.
	In operation	Silica-tipped Flourel stops will be fitted – this can be done using the jack so that at no stage is the mass unsupported. The total count is Eight around the barrel of the mass Four on the front face Four on the back face fixed to the reaction mass

3 Options for compliant earthquake stops

Although the work reported in T060053 and T060098 is not yet complete, it seems that a stop for the purposes of protecting the non-metal masses during an earthquake will be feasible having the following properties:

- We do not need to introduce artificial compliance into the structure; the stop can have as much compliance as needed
- The stop can have a silica tip
- It can be made from Flourel FC2180 or similar, which is LIGO vacuum approved.
- It may need a graded stiffness
- It needs to withstand a maximum force of order 1000N per mass; somewhat less per stop.
- We have allowed an envelope of 15mm diameter by 15mm long in the rest of the design; this should be adequate.
- The stops between the masses are special. There is only a 5mm gap, but it will not be necessary to remove energy in these stops. It may be that the analysis will show that we could use a stop consisting of, say, 2mm of silica and 2.5mm of flourel (leaving a 0.5mm gap). To be one the safe side, we are exploring the option of making holes in the reaction and Pen Re masses into which stops can be recessed so that they could be longer than 4.5mm.

Some design options are illustrated below.

	Truncated cone gives graded stiffness
	Silica tip push-fit into Flourel
	Silica tip is captured
	Backup outer cylinder (light blue) in PFA440 only acts during a severe earthquake but prevents overloading of silica tip.

4 Conclusion

We believe that the complement of stops and pads that we propose will serve the requirements well and ameliorate many of the problems that have been experienced with earthquake stops on initial LIGO. The design of the compliant stops cannot be completed until the FEA work on forces and compliance is done, but we do not think that it need stop work on the rest of the noise prototype at this stage.