LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
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Technical Note	**LIGO-E030237-00-I**	05/02/03

Double Start Counterwound Production Spring Analysis

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This is an internal working note
of the LIGO Project.

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Mass Reduction

The efforts to reduce the mass of the spring ~~of the spring~~ and in turn ~~reduce~~ increase the resonant frequencies of the offload spring (D020408 Double Start Counter wound Spring Assembly) have been accomplished largely though a central mass reduction. Material from the middle of the spring which finite element analysis (FEA) results depicted as having little involvement of the performance of the spring was removed. Additional weight reduction was accomplished by reducing the overall length of the actual spring (D020406) by one inch. FEA indicated this section was as virtually "inactive".

Of course, this ~~mitigated the~~ necessitated a change in geometry of the spring connectors (D020407) which resulted in an additional weight reduction. Further weight reductions where accomplished by lightening holes in the connector.

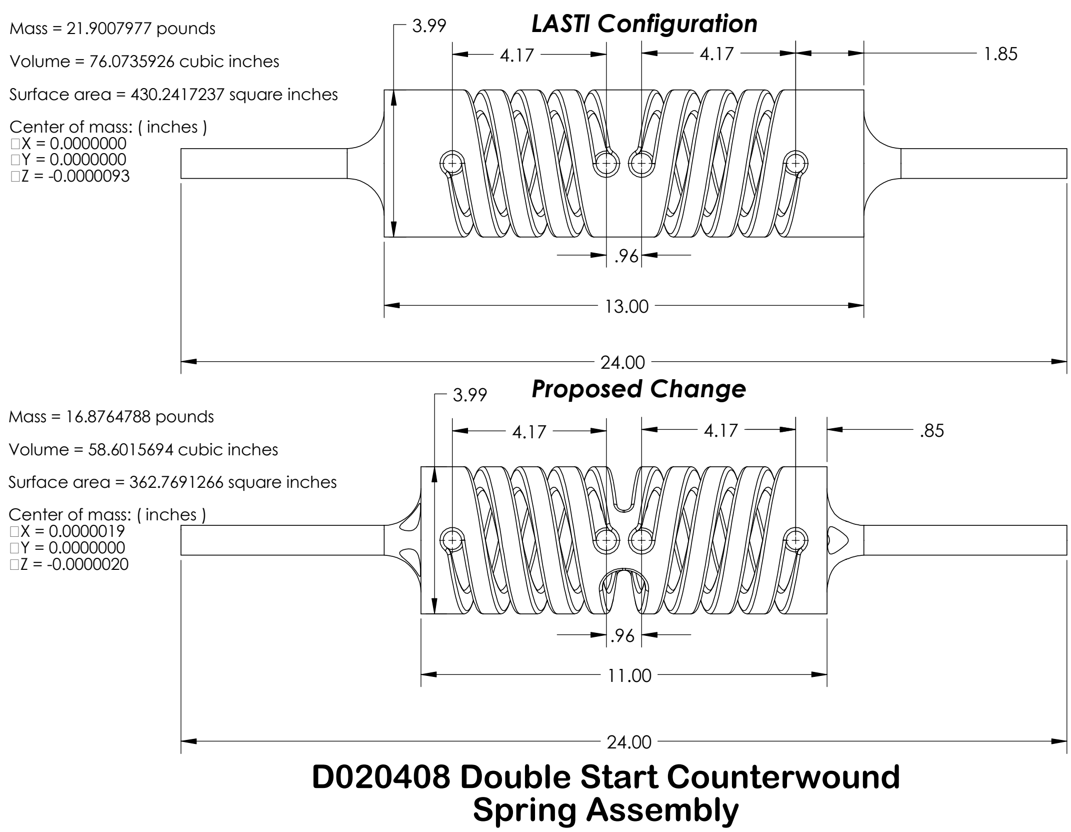

Figure 1: Spring Geometry Comparison

The resulting bottom line is that the spring mass was reduced by 22% and preliminary FEA stress results indicate a very modest decrease in the factor of safety (in the magnitude of 1% to 2 %).

Several scenarios where entertained to evaluate the greatest increase in resonant frequency and the down selections where base on those results.

Modal Analysis

After the preliminary analysis indicated that the stress levels where in an acceptable level, modal analysis where performed on the resulting candidates. Because our base line has changed, I went ahead an ran the analysis for the LASTI (as installed) configuration as well as the proposed lighter and shorter configuration. I also included an analysis of an intermediate configuration that keeps the same length as the LASTI model, but employs the central mass reduction as well as the four lightening holes in the end connectors.

Interestingly enough, it is very hard to compare FEA models in the constrained mode because no two model are exactly the same, even in the event of using the same mesh size (.325 and .1625 respectively). The models are very sensitive to the location of the of the constraints. Constraints that are further out (from the middle) result in a higher resonant frequency and the converse of that yields opposite results. Of course this is a reasonable result and indicates that we should take great care in the position of the fasteners when installed so we can better predict what resonant frequencies to expect. I am pretty certain that the offload springs at LASTI are installed .5” to 1” further away from the origin than the original analysis constraints were placed. This is because the springs are two inches longer (to accommodate installation). Effects of constraint placement will be discussed later in this report.

Because we are not quite sure just what class of boundary conditions the springs are under, I ran analysis with clamped, pinned, and free boundary conditions. The pinned analysis results where exactly the same as the clamped results , which led me to believe that the software didn’t work. But after a little more thought, I realized that the solid brick elements have no rotation so those effects would probably not have any weight on the results. The results of the free constraints resulted in the near zero modes which arise because of the six degrees of freedom that are not being constrained. Dennis Coyne reminded me that you have to tell ALGOR to expect rigid body modes through a software toggle.

Approach

For the pinned analysis, I constrained the spring on ~~there~~ each end connector 1.95 inches from the end over a distance of 1.3 inches . This is probably further away from the edge of the spring than is installed at LASTI, but for comparative purpose, it should be just fine. (I intend to ask Ken Mason to measure what the actual conditions are for the final cut)

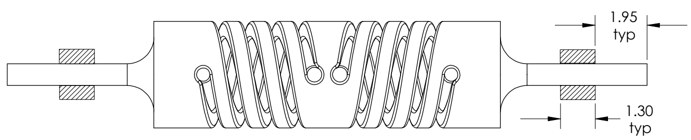

Figure 2: Spring Constraints (for pinned condition)

The mesh size for the down select round was .325 inches. Of course the physical property data was included the typical values for C300 maraging steel and 4340 steel.

Results

For ease of comparison, the results of the free constrained results best illustrates the net improvement (gain) of the resonant frequencies and are used for the down-select process. I have include the pinned results for a further comparison.

	Configuration	**LASTI (Baseline)**		**Proposed Configuration**		**Central Mass Reduction with End Connector Mass Reduction**	
		Free	Clamped ~~Pinned~~	Free	~~Pinned~~	Free	~~Pinned~~
1st Bending	~~Running~~ mode 1	112.08	134.521	128.70	134.96	114.93	142.66
1st Bending	~~Running~~ mode 2	114.43	136.62	129.85	137.46	115.70	144.93
1st Extensional	~~Drum~~ mode 1	180.799	214.38	217.50	214.06	181.64	234.07
1st Radial	~~Drum~~ mode 2	195.87	N/A	241.27	N/A	195.62	N/A
2nd Bending	~~"S"~~ mode 1	255.78	277.30	266.51	291.75	257.70	281.70
2nd Bending	~~"S"~~ mode 2	257.64	280.06	272.01	294.67	261.95	283.24

Baseline Plot Results

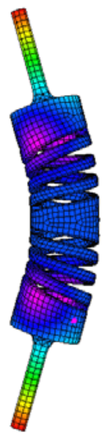

Figure 3: LASTI Baseline ~~Running~~ 1st BendingMode 1 (free constraints)

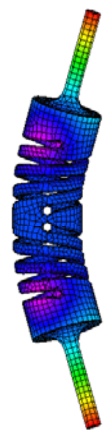

Figure 4: LASTI Baseline ~~Running~~ 1st BendingMode 2 (free constraints)

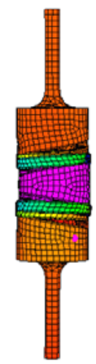

Figure 5: LASTI Baseline ~~Drum~~ Extensional Mode 1 (free constraints)

Figure 6: LASTI Baseline ~~Drum~~ Radial Mode 2 (free constraints)

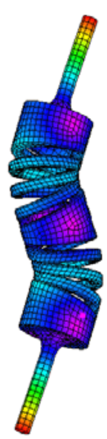

Figure 7: LASTI Baseline “~~S~~” 2nd BendingMode 1 (free constraints)

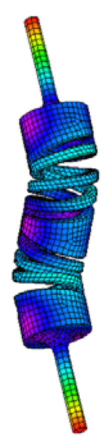

Figure 8: LASTI Baseline “~~S~~” 2nd bending Mode 2 (free constraints)

Figure 9: LASTI Baseline Running Mode 1 (pinned constraints)

Figure 10: LASTI Baseline Running Mode 2 (pinned constraints)

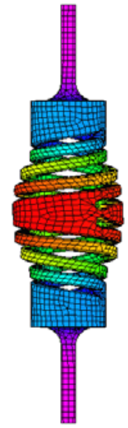

Figure 11: LASTI Baseline Drum Mode 1 (pinned constraints)

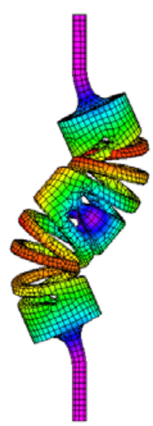

Figure 12: LASTI Baseline "S" Mode (pinned constraints)

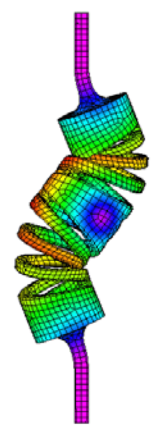

Figure 13: LASTI Baseline "S" Mode 2 (pinned constraints)

Proposed Configuration Plot Results

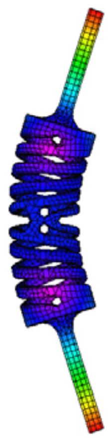

Figure 14: Proposed Configuration Running Mode 1 (free constraints)

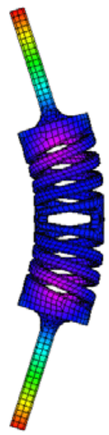

Figure 15: Proposed Configuration Running Mode 2 (free constraints)

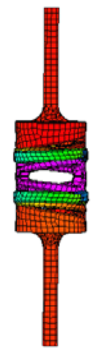

Figure 16: Proposed Configuration Baseline Drum Mode 1 (free constraints)

Figure 17: Proposed Configuration Drum Mode 2 (free constraints)

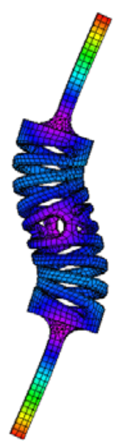

Figure 18: Proposed Configuration "S" Mode 1 (free constraints)

Figure 19: Proposed Configuration "S" Mode 2 (free constraints)

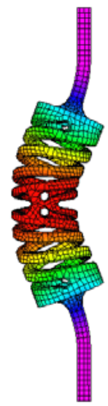

Figure 20: LASTI Baseline Running Mode 1 (pinned constraints)

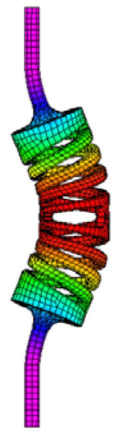

Figure 21: LASTI Baseline Running Mode 2 (pinned constraints)

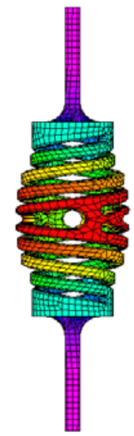

Figure 22: LASTI Baseline Drum Mode 1 (pinned constraints)

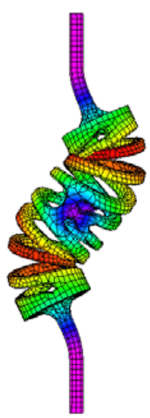

Figure 23: LASTI Baseline "S" Mode (pinned constraints)

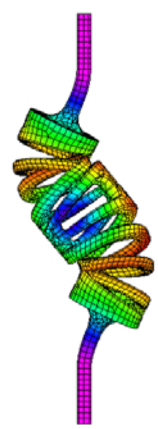

Figure 24: LASTI Baseline "S" Mode 2 (pinned constraints)

Clearly, the comparison between the LASTI configuration and the Proposed configuration yields a substantial gain in resonant frequency. When comparing only the free constrained condition, the resonant frequency increased by 20.02%. It could be further argued that this weight reduction scheme is more favorable that the third scheme presented (Central Mass Reduction with End Connector Mass Reduction).

Although we would like to believe that this is the actual gain, common sense and experience predicate refining the model to gain a better sense of the true nature of the weight reduction.

The mesh size was decreased by a factor of two (.1625") and the analysis was rerun for the following four conditions:

- LASTI Baseline free constrained condition
- LASTI Baseline pinned constrained condition
- Proposed Configuration free constrained condition
- Proposed Configuration pinned constrained condition

Configuration	***LASTI (Baseline)***		***Proposed Configuration***	
	Free	Pinned	Free	Pinned
Running mode 1	83.64	125.26	93.56	125.26
Running mode 2	85.33	126.02	94.33	126.74
Drum mode 1	132.15	188.83	153.59	192.3
Drum mode 2	156.09	N/A	188.02	N/A
"S" mode 1	193.74	236.02	198.37	243.82
"S" mode 2	194.41	238.42	200.91	244.28

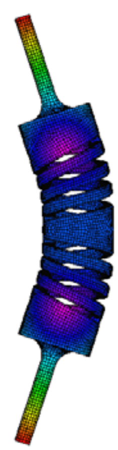

Figure 25: LASTI Baseline Running Mode 1 (free constraints)

Figure 26: LASTI Baseline Running Mode 1 (pinned constraints)

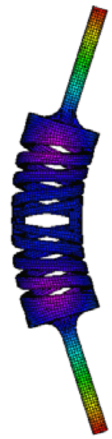

Figure 27: Proposed Configuration Running Mode 1 (free constraints)

Figure 28: Proposed Configuration Running Mode 1 (pinned constraints)

The results of the refined model, while not offering such as large increase, does offer a more reasonable result. Comparing the free constrained condition, the gain in resonant frequency is advertised as 11.86%. I feel more comfortable with this result as a previous batch of results indicated similar results and was advertised in my last weeks weekly update.

In order to gain confidence in the modal analysis results, Jonathan Kern led me down a path to collect data via the frequency analyzer and microphone setup. The spring was suspended by a wire and bumped with a calibrated wire cutter. Although the tests were performed numerous times, for the sake of brevity, I have only included one set of results. (It is worth mentioning that the a baseline data of the ambient noise was taken and was subsequently subtracted from the bump test data) While the setup may be crude, I do feel that a) the it is a reasonable approach, and b) the data does correlate reasonably well with the analyzed results.

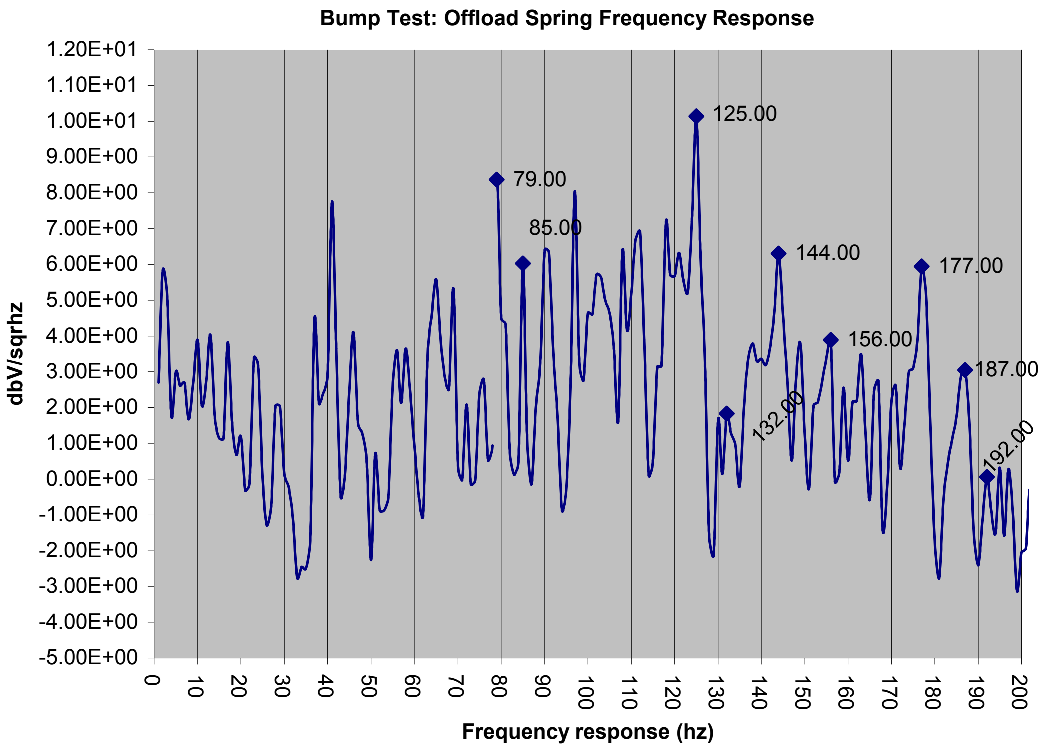

Figure 29: Frequency Response Plot

I have highlighted the interesting peaks for consideration and welcome any comments that you could afford. Of course there is still much to be learned about the results and there are several factors that still concern me:

First and foremost, the fact that even though the mesh size is specified, I can't guarantee the resulting size of the mesh which in turns lends itself to error in a comparative analysis. Furthermore, I am not sure what the resulting two drum modes (as a result of an unconstrained boundary condition) mean and why my results don't produce a drum mode similar to the constrained condition. I am sure it has to do with the fact that the mass at the end can move, but I don't yet understand the mechanism.

All-n-all, I am confident that the proposed mass reduction does result in a substantial increase in resonant frequency and that it merits the rework of the spring. At present, my intent is to run a third party verification of the mode shapes using ANSYS, and am waiting for your input and concerns.

Constraint Evaluation

Coming soon

Static Stress Analysis

Pending review

Final Production Drawings

Pending review

Spring stiffness Matrix formulation of Production Spring

Pending Review