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LIGO Coil Spring Testing

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Abstract

The active component of the LIGO project isolation system is an internally damped coil spring, patented by HYTEC. Each optic table will be supported by 144 of these coil springs. The spring manufacturer (Pegasus) will send a portion of the springs to HYTEC for testing.

The (ongoing) goal of these tests is to predict the performance of the isolation systems, by determining a statistically meaningful loss factor and stiffness (h and *K*) for the coil springs. The test results will also be used to determine the final construction methods and materials for the springs. Three types of springs have been tested to date; those assembled with Epoxy I, Epoxy II, and with no epoxy. Individual springs were tested, analyzed, and an average loss factor and standard deviation for each class of springs determined. In addition, fatigue testing will be performed to determine the effect of a large number of cycles on the spring characteristics.

The spring characteristics were determined using a free-decay pendulum designed and built at HYTEC, and enclosed in a temperature controlled box for testing.

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LIGO PROJECT

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1. Summary

This report documents the test setup, temperature control requirements, and the test results in terms of damping and stiffness for three different LIGO coil spring configurations. A summary of the major results is given in Table I.

Configuration	Average Loss Factor (%)	Corrected Loss Factor (%)	Standard Deviation	Average Stiffness (N/m)	Number in Sample
Epoxy I	2.42	2.37	0.33	43,000	403
Epoxy II	2.60	2.55	0.16	42,700	15
No Epoxy	2.34	2.29	0.16	41,090	52

Table I Summary of test results.

Based on the large standard deviation of the Epoxy I springs, statistically meaningful comparisons between the three types of springs are not possible at this time. The results in the report are uncorrected unless otherwise noted.

2. Coil Spring Test Apparatus and Procedure

2.1 General test setup

Figures 1 and 2 show the test apparatus in a closed box configuration and in a open box configuration, respectively. Figure 2 shows the pendulum test apparatus used in all previous HYTEC spring vibration decay measurements[1,2,3]. The box structure enclosing the spring test apparatus and associated temperature control equipment is used to ensure that the springs are tested at the desired temperature level.

Figure 1: Test apparatus in closed box configuration.

Figure 2: Test apparatus in open box configuration showing pendulum test setup.

The control box fits entirely over the decay pendulum, and access is through two doors located on the side and in the top of the box. The heater/cooler unit was installed in one corner of the box, and included a fan to circulate the tempered air. An additional fan was installed at the opposite diagonal of the box.

2.2 Damping measurement system

A Kaman KD-2300 position sensor was used to measure displacement of the free-decay pendulum from centerline, with the output recorded on an oscilloscope. The coil springs were installed individually and compressed to balance the pendulum. Time was allowed for the Viton seats holding the spring to compress, and the pendulum was set into oscillation. The decay curve was recorded on an oscilloscope, and analyzed using a MATLAB[4] script fileto extract the loss factor and stiffness. The same pair of Viton seats were used for all tests.

2.3 Required temperature control

The first 100 springs (all constructed with epoxy I) were tested in an open room, with the air temperature near the subject coil spring being measured by a digital thermometer. It was later found this thermometer was reading high by approximately 0.7 C°. The temperature for these tests was therefore 20.3 +/- 1.0 C°. Rapid swings in temperature of +/- 2 C° were registered. An insulated box was constructed and used to test the remaining springs. The temperature in this box was maintained at 21.0 +/- 0.1 C° using a solid state heater/cooler and an electronic controller. Temperature was read using a 3-wire 100-ohm platinum RTD. The RTD was tested in an ice bath during the initial week of use in the temperature control box, and read 0.0 C°. The test was repeated in July and gave the same results.

The first 30 springs or so were tested multiple times, and the results were found to be quite repeatable (within a 3% ratio as measured by comparing loss factors) as long as temperatures were within 0.1 degrees. The temperature control box was utilized for all tests after June 1st, corresponding to all Serial Numbers above #1101. After the temperature control box was brought on line, multiple testing was reduced to approximately 1 spring in 30. To further insure no fixed errors were present, a single spring was tested repeatedly at regular intervals (after approximately every 18 springs). The results of these tests on prototype DC07 are plotted in Figure 3 as loss factor (η) as a function of test date.

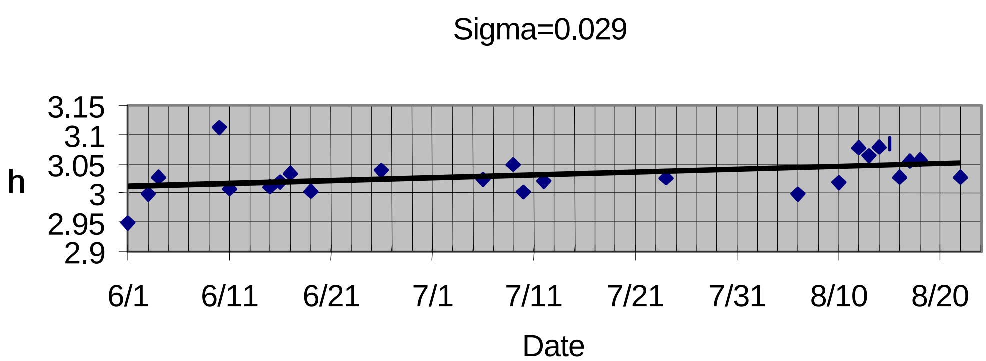


Figure 3: Loss factors for Prototype DC07 (raw data).

3. Test Results

3.1 Epoxy I springs

Twelve shipments (Ship I-XII) of coil springs assembled with Epoxy I were received from Pegasus, for a total of 403 springs. Serial numbers for these springs were from DC1000-DC1423. The shipments were received from March 20 through May 15.

The average measured loss factor for the 403 springs was 2.42%, (median 2.46%) and the average stiffness was 43,000 N/m (median 43,020 N/m). The standard deviation was 0.33%. A total of 361springs with loss factors between 2.0 and 3.0 were shipped from HTYEC for cleaning. The adjusted average loss factor for the shipped springs was 2.46% (median 2.48%) and the average stiffness was 42,960 N/m (median 42,920 N/m). The loss factors (h) for all 403 springs tested are plotted in Figure 4 below as a function of serial number. Serial numbers not received from the manufacturer are plotted as a loss factor of zero. The colors represent shipments from the manufacturer.

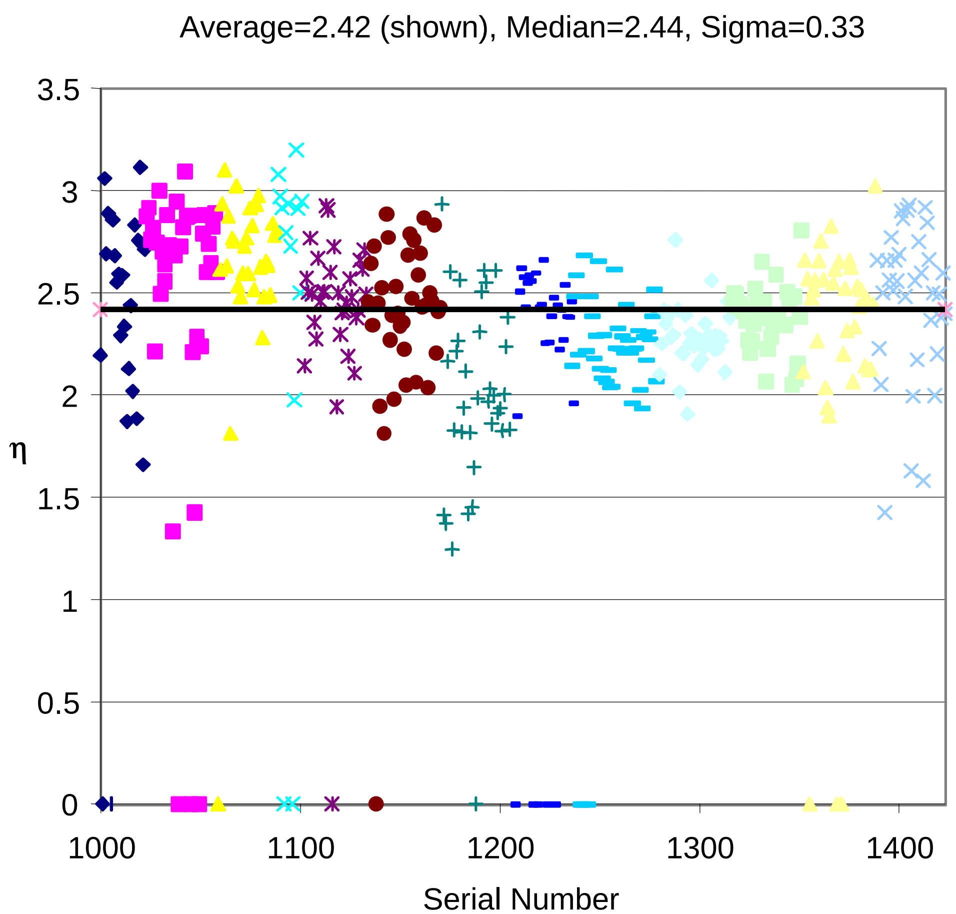


Figure 4: Loss factors for 403 springs with epoxy I (raw data).

3.2 Epoxy II springs

A single shipment of 15 springs with epoxy II was received from Pegasus on August 5, with Serial Numbers 3000-3014. The average loss factor was 2.61% (2.59% median), and the standard deviation was 0.16. The average stiffness was 42,700 N/m (median 42,510 N/m). The loss factors for the special epoxy springs are graphed in Figure 5 below.

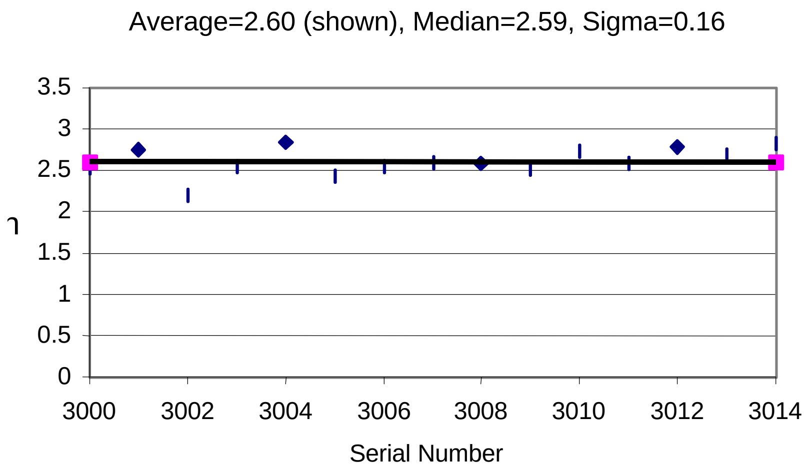


Figure 5: Loss factor for 15 springs with epoxy II (raw data).

3.3 Springs without epoxy

A total of 51 springs (shipments XIII and XIV) with no epoxy were received from Pegasus, with Serial Numbers 5000-5051. The shipments were received from July 21 through August 5. Each of the springs was tested using a free decay pendulum. The average loss factor for the no epoxy springs was 2.34%, (median 2.37%) with a standard deviation of 0.16%. The average stiffness was 41,090 N/m (median 40,980 N/m). The loss factors for the no epoxy springs are graphed in Figure 6 below.

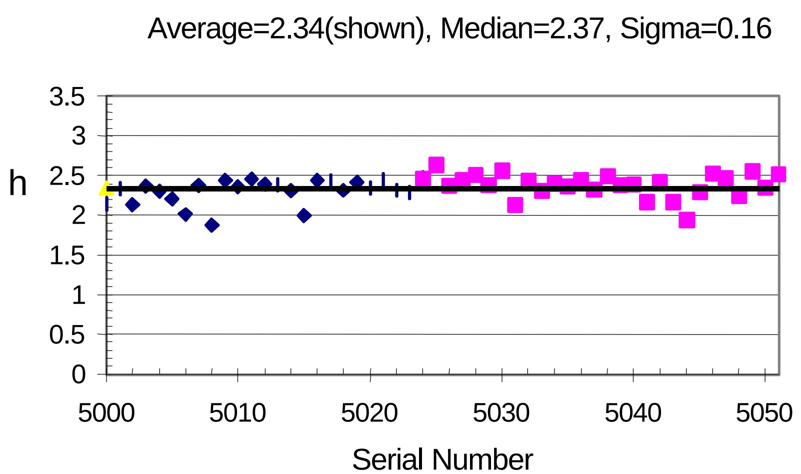
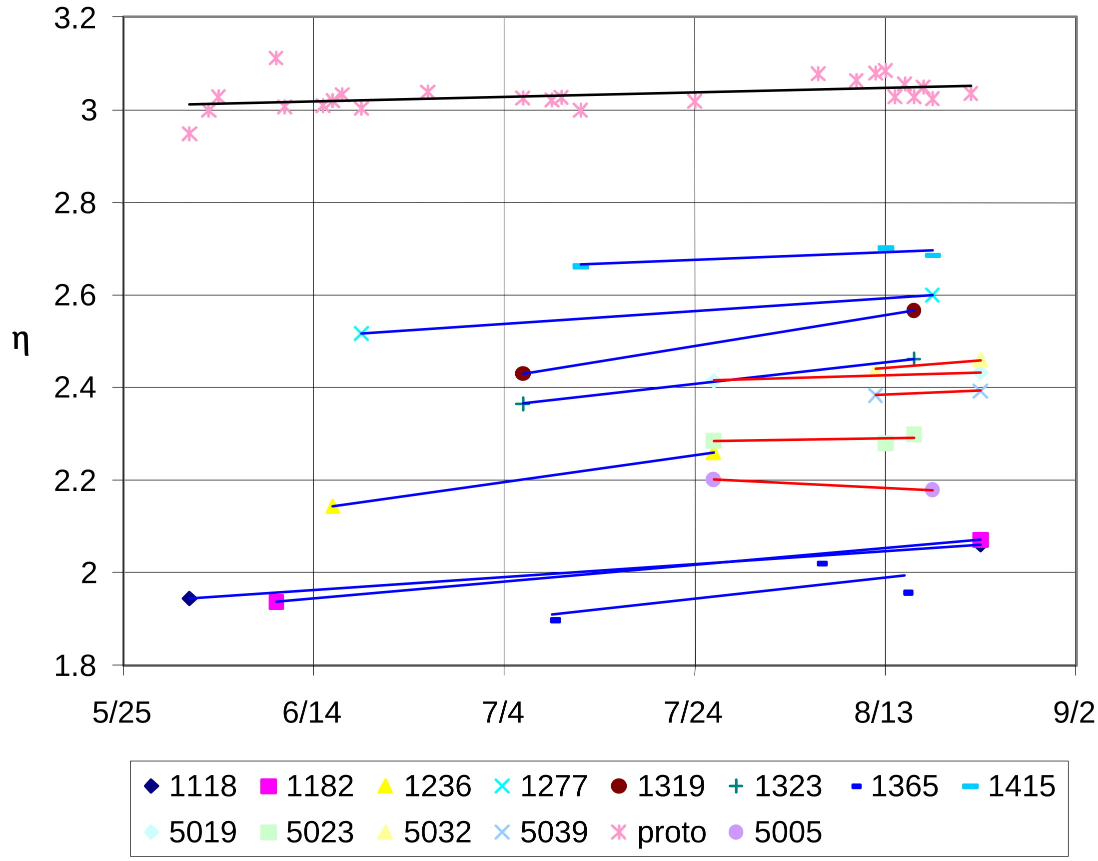


Figure 6: Loss factor for 52 springs without epoxy (raw data).

4. Discussion of Results

Tests of the prototype DC07 show a slight increase in loss factor over the course of testing in the temperature control box. Because of this trend, several other springs that had been retained at HYTEC were re-tested. The results of these tests are shown below.



Blue trend lines-epoxy I Red trend lines-no epoxy Black trend line-prototype

Figure 7: Loss factors for various springs (raw data).

The general trend is an increase in loss factor ratio (change in loss factor divided by original loss factor) from 1-10% over a period of approximately four months. Effort has been made to determine if this trend is caused by an increasing fixed error with the testing apparatus, but no particular problem has been found.

It is plausible that a slow reaction is occurring inside the coil springs. One possibility is that the viscous damping layer (Soundcoat DYAD 606) is stiffening with time. There is also a possibility that the epoxy is accelerating this reaction, since the no-epoxy springs tested don’t show the same trend. This is difficult to quantify at this time due to a lack of historical data on the springs without epoxy. The springs with Epoxy II were not tested for the same reason. HYTEC plans to retain several of each type of spring for continued monitoring. It is possible that the reaction is temperature sensitive, and in this case could be positively identified by holding a sample spring at an elevated temperature and comparing before and after test results.

One fixed error has been noted in the apparatus. The temperature controller was programmed for an RTD with an American standard slope of 0.00392 ohms/ C°, while the purchased RTD actually has the European standard slope of 0.00385 ohms/ C°. This causes the temperature reading to be approximately 0.375 C° low. Instead of changing the controller setting midway through the testing, a correction factor will be applied to all the data at the end of the testing. At this time, an expected value of adjustment is to decrease the loss factor by a multiplier of 0.02. This correction factor is based on testing data from the prototype spring DC07. Additional tests will be done with springs having loss factors of 2.0 and 2.5% to verify that the correction is linear.

5. References

1. E. Ponslet, *Low Frequency Damping Measurement Setup and First Results*, HYTEC Inc., Los Alamos, NM, document HYTEC-TN-LIGO-17, June 1997.
2. F. Biehl, *Temperature Effects on LIGO Damped Coil Springs,* HYTEC Inc., Los Alamos, NM, document HYTEC-TN-LIGO-18, July 1997.
3. F. Biehl, *LIGO Damped Coil Spring Test Data - Non Welded and Welded Springs,* HYTEC Inc., Los Alamos, NM, document HYTEC-TN-LIGO-22, July 25, 1997.
4. MATLAB, The Language of Technical Computing, The Math Works, Inc.

Note 1, Linda Turner, 09/03/99 02:52:10 PM
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