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BSC Prototype Welded Diaphragm Bellows Test Report

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Abstract

This report summarizes the results from mechanical tests conducted by Senior Flexonics on a prototype BSC bellows. The tests were intended to provide data on spring rates, life, leak rates, and behavior under axial twist. The test report from Senior Flexonics is attached.

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LIGO PROJECT

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1. BSC Bellows - Requirements

During Operation of the BSC SEI system, the bellows are subject to axial, shear, and twist deformations due to actuator motions, structural deflections, and manufacturing tolerances. Reference [1] describes these factors, evaluates their magnitudes, and combines them to obtain the following deflection requirements:

- axial: 13.9 mm (0.548")
- shear/transverse: 18.1 mm (0.714")
- twist: 1.32 mrad (0.076°)

Note that the twist requirement was derived for an actuation system with translations and yaw capabilities only (see [1]). A recently introduced requirement to provide for 0.5 mrad (TBD) (0.029°) roll and pitch motion capabilities would change the above requirements to:

- axial: 13.9 mm (0.548")
- *shear/transverse: 18.3 mm (0.720")*
- *twist: 1.82 mrad (0.104°)*

Note that the axial requirement is not affected and the shear requirement is only slightly increased (1.1% increase) while the twist requirement goes up by more than 35%.

In addition, any leakage is limited to a maximum of 10^{-10} torr.liter/sec of Helium.

2. Test Plan

A Hytec test plan is described in reference[2]. That plan was used as a starting point for developing the attached Senior Flexonics test plan QTP 47072.

Note that both test plans are based on the design requirements prior to addition of the roll and pitch requirements. However, additional twist testing was added to cover higher twist deformations (see sections 3.7 and 3.8 of QTP47072).

3. Test Results

The test report QTR 47072 obtained from Senior Flexonics is attached to this document. The following is a short summary of those results. Refer to QTP 47072 and QTR 47072 for description of the test fixtures, instrumentation, and procedures.

3.1 Leak Testing

Throughout the mechanical testing program, leak tests were performed repeatedly to detect any degradation from mechanical deformation of the bellows. Because of test conditions and equipment, the prototype could only be tested to 1.5 10^{-9} scc/sec. No change in leak rate was observed from beginning to end of the mechanical testing.

3.2 Spring Rates

3.2.1 Axial

The results from pure axial tests (page 11 of QTR 47072) are plotted in Fig. 1. Note the excellent repeatability from cycle to cycle and the linearity. Least square linear fit to the data gives an axial spring rate of 6017 N/m (34.4 lb/in).

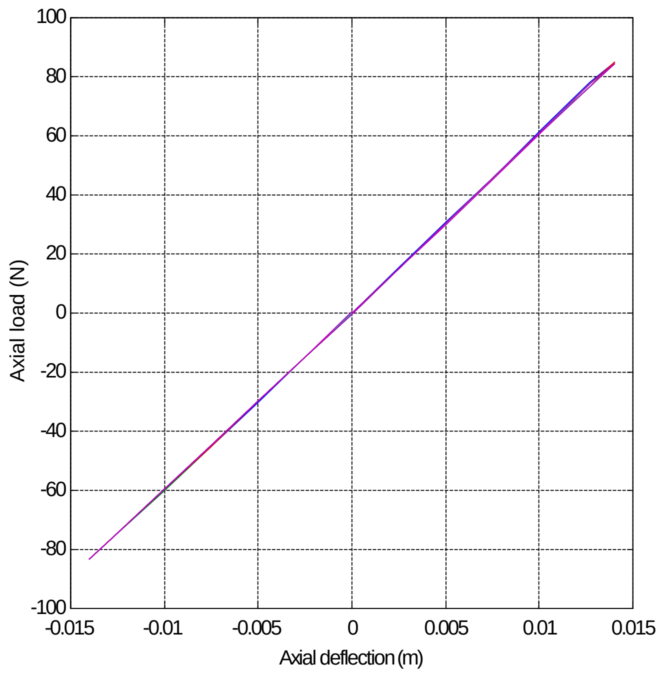

Figure 1: Axial testing of BSC bellows prototype - experimental results; all 5 load/unload cycles are shown.

3.2.2 Shear

The results from pure shear tests (page 12 of QTR 47072) are plotted in Fig. 2. These results show more dispersion and a dry friction-like hysteresis. This can probably be attributed to friction in the linear bearings that are part of the shear test fixture (see QTP 47072). Least square linear fit to the data gives a shear spring rate of 43658 N/m (249.3 lb/in).

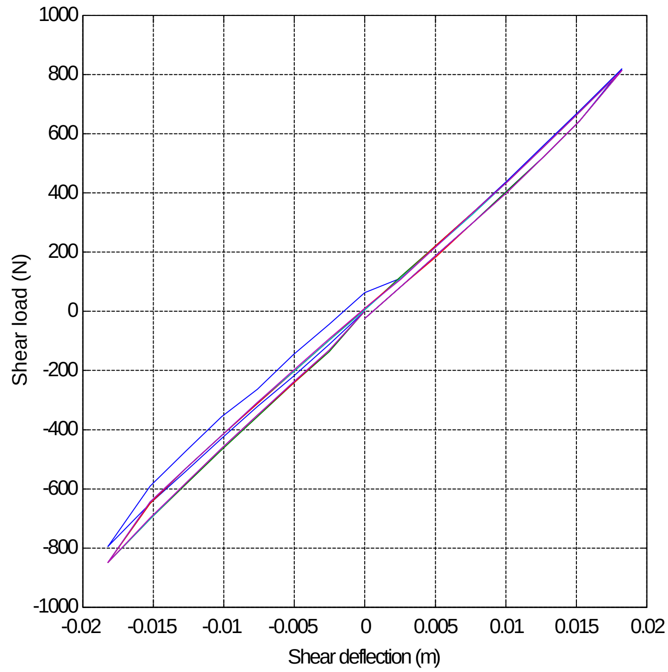

Figure 2: Shear testing of BSC bellows prototype - experimental results; all 5 load/unload cycles are shown.

3.2.3 Twist

The results from pure twist tests (page 13 of QTR 47072) are plotted in Fig. 3.
Note: there is a systematic transcription error in QTR 47072; the measured deflections for the CCW cycles should be multiplied by -1 throughout (confirmed by Peter Driscoll, Senior Flexonics).
Least square linear fit to the data gives a twist spring rate of 263150 N-m/rad (40652 in-lb/deg).
The data also appears to show a slight softening in twist from small to large twist angles. This is likely due to the beginning of a twist buckling instability due to small imperfections (we are clearly well below the theoretical twist buckling angle).

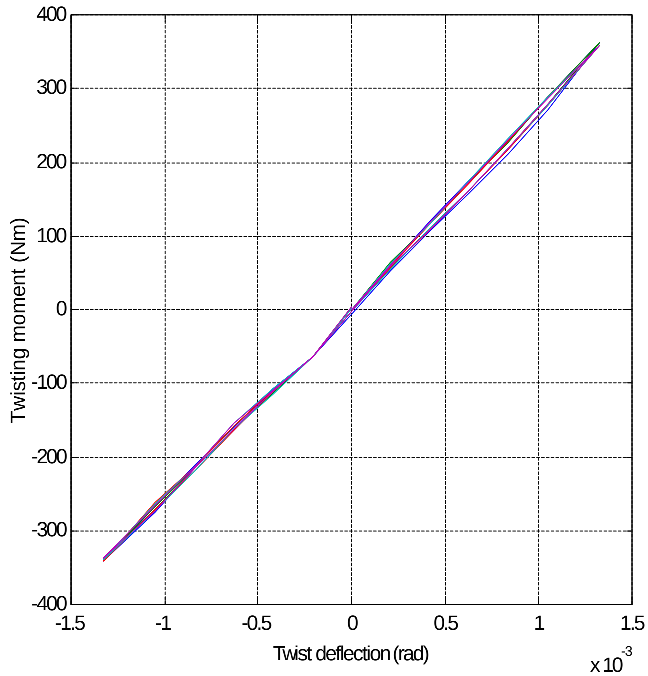

Figure 3: Twist testing of BSC bellows prototype - experimental results.

3.3 Fatigue Tests

The bellows was cycled through 2000 full deflection cycles both in shear (with superimposed fixed axial compression) and in twist (with fixed axial and shear deflections). No visible damage or signs of rubbing were detected during those tests. Subsequent leak testing did not show evidence of any leaks.

3.4 Increased Twist Tests

To gain experience with the behavior of metal welded diaphragm bellows under large angle axial twist, we performed additional tests at twist angles largely in excess of those expected in operation. These extended tests are also intended to indicate whether pitch and roll actuation requirements can safely be added without risk for the bellows.

3.4.1 Twist fatigue test with fixed axial and shear deflections

The twist cycling test of section 3.3 was repeated for a twist angle of 0.105° (corresponding to an added requirement for 0.5 mrad TBD of roll actuation, see section 1). Again, no damage, rubbing, or leak was observed.

3.4.2 Large twist angle test

Starting with a fixed 0.551" compression and 0.717" lateral offset, the bellows was slowly twisted to an angle of 2.38 degrees without causing permanent deformation or major instability. This gives us a factor of safety of at least 23 for resistance to single stroke twist.

3.4.3 Additional Twist Cycling

As a final check, we asked Senior Flexonics to perform 5 complete cycles of twist deformation at ±0.228° (3 times the original ±0.076° requirement), without superimposed axial or transverse deflection. Again, this test did not lead to any visible damage, rubbing marks, or leaks.

4. Conclusions

A series of tests were conducted to qualify the current design for the BSC support beam bellows in terms of its resistance and fatigue life under combined axial, transverse, and twist deformations. All test results show that the bellows is able to endure both the magnitude and the number of cycle expected in operation (25 year life) of the LIGO detectors. In particular, the capacity of the bellows to endure large twist deformations largely exceeded Senior Flexonics expectations and indicates the possibility of adding roll and pitch actuation requirements of the order of ±0.50 mrad (TBD).

Note: the roll and pitch angular motion requirement is now set to +/- 1.5 mrad. It should be noted that, although there is a good chance that the bellows will be able to endure the increased twist and shear deflections, no fatigue data is available to support this.

5. References

1. E. Ponslet and B. Weinstein, *Determination of Deflection Requirements for BSC Support Beam Bellows*, HYTEC Inc., document HYTEC-TN-LIGO-08a (revision *a*), January 1997.
2. *BSC Support Beam Bellows Prototype - Fabrication Requirements and Test Plan,* HYTEC Inc., document HYTEC-TS-LIGO-01, January 1997.

6. Attachments

1. Peter L. Driscoll, *Qualification Test Procedure for LIGO BSC Prototype Expansion Joint*, Senior Flexonics Metal Bellows, document QTP 47072, May 19, 1997.
2. Peter L. Driscoll, *Qualification Test Report for LIGO BSC Expansion Joint Prototype*, Senior Flexonics Metal Bellows, document QTR 47072, July 29, 1997.

Note 1, Linda Turner, 09/03/99 02:21:40 PM
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