LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO-T030124-01-D *LIGO* 4 July 2003

Hydrostatic testing results of bellows for the HEPI actuator

Jonathan Kern

Distribution of this document:
LIGO Science Collaboration

This is an internal working note
of the LIGO Project.

California Institute of Technology
LIGO Project – MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project – NW17-161
175 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 1970
Mail Stop S9-02
Richland WA 99352
Phone 509-372-8106
Fax 509-372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone 225-686-3100
Fax 225-686-7189

http://www.ligo.caltech.edu/

1 Introduction

1.1 Background

Following the assembly of the first HEPI actuator in October, 2002, leaks were detected where the bellows is welded to its weld assist ring. Hydrostatic testing was conducted and a different weld assist ring was designed to correct the problem.

Anticipating the production of ~90 or more actuators for the LLO seismic retrofit, bellows were manufactured of 304L and 17-7ph stainless steel alloys, and subjected to more systematic hydrotesting. This report documents the June 2003 test of the 304 SS and 17-4 PH SS HEPI bellows. Briefly mentioned are the results from the testing done on the 304 SS bellows in November 2002.

1.2 Scope

In this technical note, hydrotesting results are reported and recommendation is made for the alloy selection.

1.3 Referenced Documents

T020173-00-E *HEPI Bellows Leak Oct 9 2002*
T020180-00-E *HEPI Results of Vacuum Brazing Oct 31 2002*
T020181-00-E *HEPI Vacuum Brazed Bellows Hydro-test Nov 1 2002*
T020182-00-E *HEPI Un-annealed Bellows Hydro-test Nov 3 2002*
T020183-00-E *HEPI Un-annealed Bellows Hydro-test Nov 5 2002*
T020184-00-E *HEPI Ameriflex Bellows Nov 9 2002*
T020185-00-L *Quite Hydraulic Actuation Bellows Design Considerations*

2 Testing

2.1 2002 testing

The 304 SS Bellows test conducted in November 2002 was done quickly due to the time constraints building the Actuators. Aluminum plates were used with an O-Ring to seal the bellows. Pressure was applied with a small hand operated mechanical pump. The bellows had to be clamped into the O-Ring gland and displacement was measured with indicators only at two locations on either side of the bellows. The results indicated that the non-annealed bellows did gain a bit of work hardening during rolling, with an ultimate failure pressure of about 200 PSI. One bellows that was annealed during the vacuum brazing failed at a lower pressure. The problem with this test arrangement was that the bellows could have started to yield at a location other than where the indicators were located and gone undetected.

2.2 2003 testing

2.2.1 Background

An improved arrangement was provided for the June 2003 bellows testing. The test was designed to measure the yielding of the bellows at any location on its surface. A total of six bellows were tested with water and a nitrogen head. Three were made with 304 SS and three of 17-7 PH SS. The bellows were welded to two flanges made of 304 SS with a geometry corresponding to their respective actuator parts. These plates were bolted together with 0.5" bolts and held apart with spacers at the correct spacing. This assembly was filled with water and placed in an enclosed container which was 95% filled with water. (**Figure 2**) This was done for thermal stability and to increase the sensitivity of the test. A sensitive pressure gauge, 0 to 40 inches of water, was connected to the chamber. As the pressure was increased inside the bellows, it expanded, thus displacing the volume in the chamber and increased the external pressure that was read on the gauge. The 304 SS bellows were tested in increments of 20 PSI and the 17-7 PH bellows were tested in increments of 50 PSI.

This new test conducted in June 2003 of the 304 SS bellows resulted in two failures at 200 PSI and one at 180 PSI. This appears to be a bit lower and could possibly be due to the welding and the fact that it was a different test arrangement. Some yielding is also noticed at about 50 to 100 PSI lower than the failure pressure.

The 17-7 PH SS bellows survived to a much higher pressure. The 17-7 PH SS bellows failed at 450 PSI, 500 PSI, and 550 PSI. Also note that there was no apparent yielding before the failure of the 17-7 PH SS bellows.

Here are comments on the heat-treating of the 17-7 PH bellows from the manufacturer, Ameriflex:

> *The bellows were taken to 1400 F for 90 minutes and then cooled to 0 C for 30 min. At this point they were returned to Ameriflex upon which a final set was done. Then the bellows were brought to a temperature of 1050 F for 90 minutes then cooled to room temperature. This completes the heat treating. This procedure is referred to as TH-1050. The hardness after heat treating to TH-1050 is RC 38 to 44 which brings the tensile yield to 180,000psi.*

Ameriflex used the TH-1050 heat treat procedure opposed to other heat treating because of their past experience with another product they manufacture. This may not be the optimum heat treat procedure for the HEPI bellows. There are some other heat-treat procedures that will result in a higher yield strength.

2.2.2 Test Results

NOTE: The actual value of the external pressure in Inches of H_2O relative to the internal pressure in PSI was different for each test. This was because of the different amounts of water in the chamber for each test. It was very sensitive to the remaining volume of air. Regardless of how accurately it was filled, there remained a slight difference.

Figure 1: 304 Stainless Steel Bellows Pressure Test Results

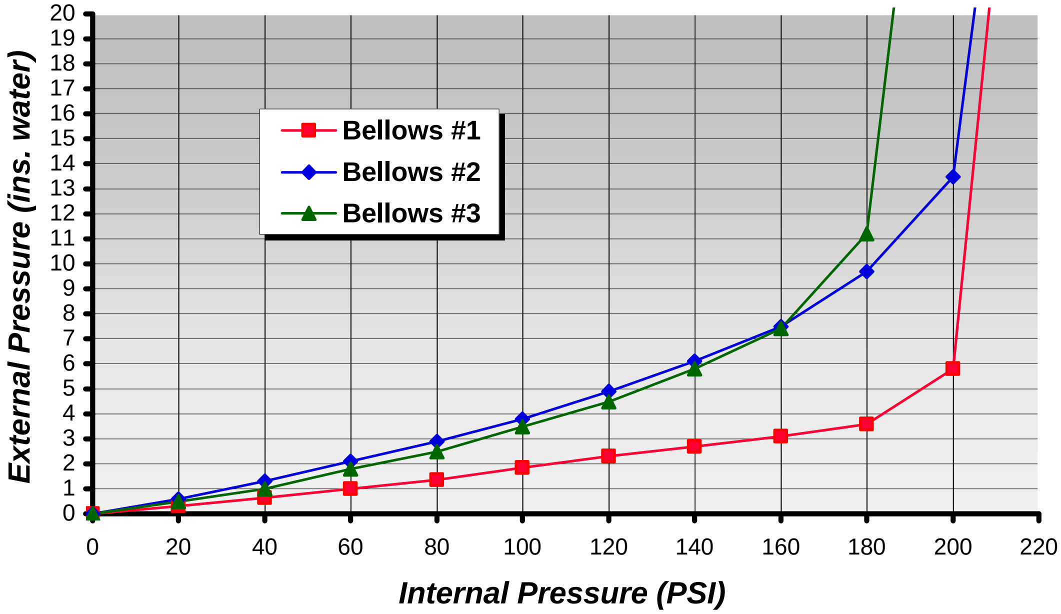

Figure 2: 17-7 PH Stainless Steel Bellows Pressure Test Results

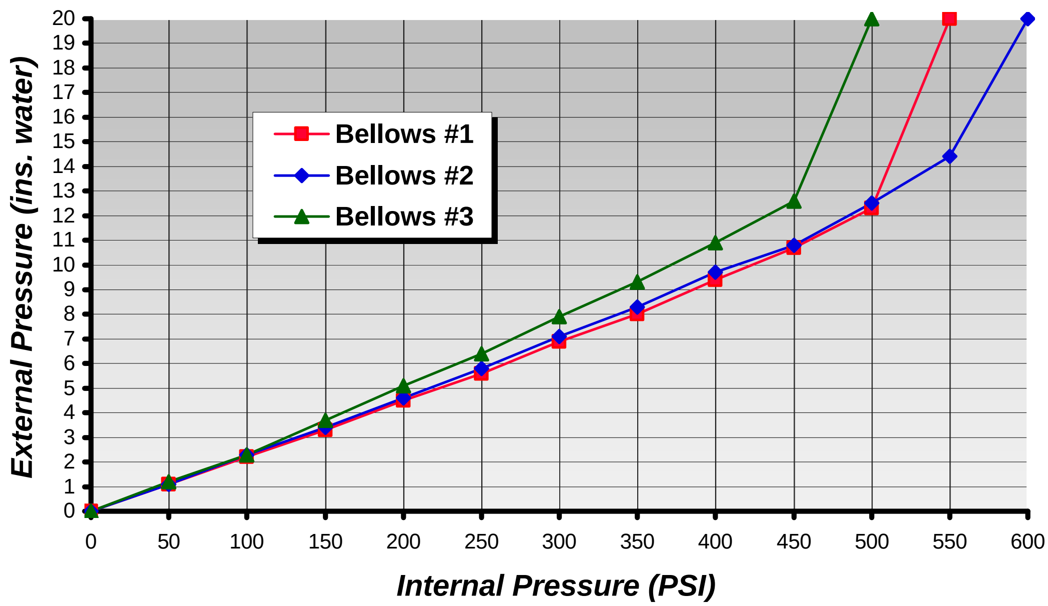

Table 1: 17-4 PH Heat-treat Options
(Sousa Corp; http://www.sousacorp.com/material.htm#17-7 PH**)**

CONDITION	HARDNESS HRC	FORM	TENSILE psi (Mpa)
RH 950	42 TO 49	Sheet, Strip	210,000 (1450)
RH 950	42 TO 49	Plate	200,000 (1380)
RH 950	42 TO 49	Bar	185,000 (1275)
RH 1000	41 TO 46		
RH 1050	40 TO 45	Sheet, Strip, Plate	180,000 (1240)
RH 1050	40 TO 45	Bar	170,000 (1175)
RH 1075	38 TO 43		
RH 1100	34 TO 40	WROUGHT	150,000 (1035)
TH 950	42 TO 48		
TH 1000	40 TO 46		
TH 1050	38 TO 44	Sheet, Strip, Plate, Welded Tubing	180,000 (1240)
TH 1050	38 TO 44	Bar	170,000 (1178)
TH 1075	37 TO 42		
TH 1100	34 TO 39		

Figure 3: The bottom bellows are 304 SS and the top bellows are 17-7 PH

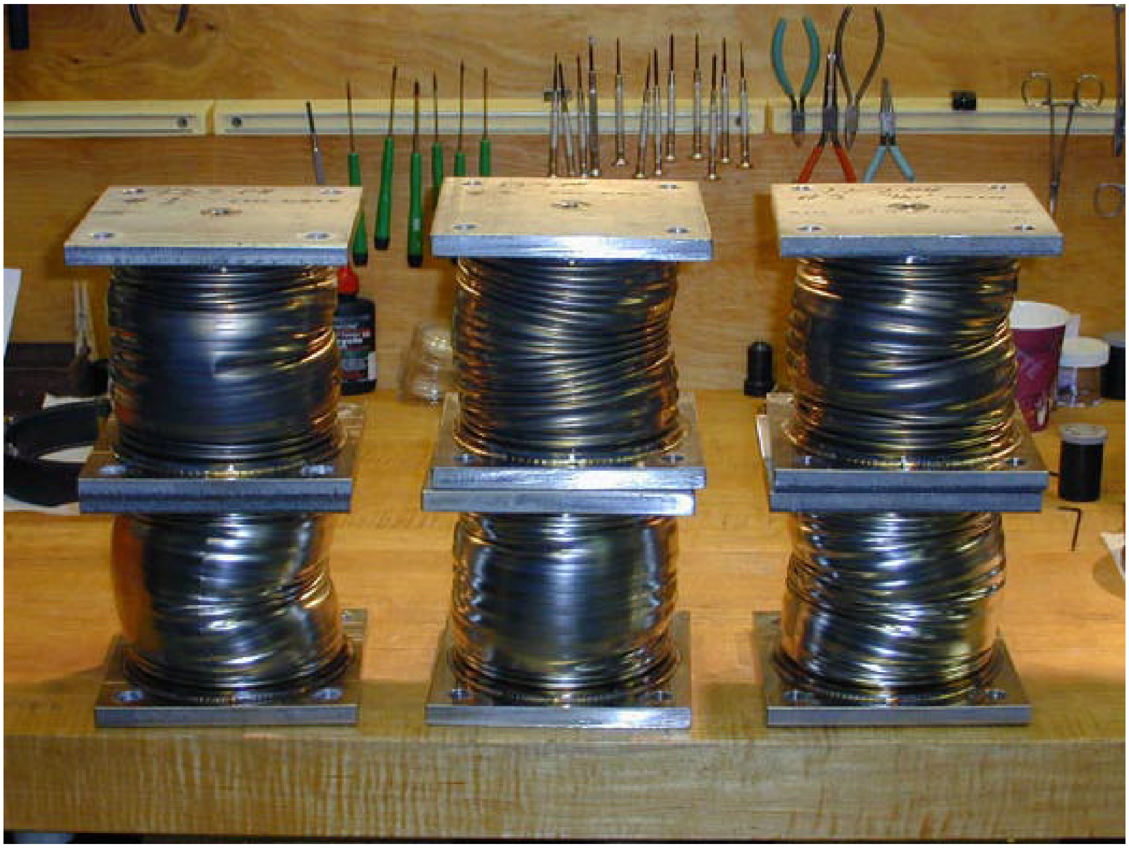

Figure 4: Test assembly filled with water and placed in an enclosed container which is 95% filled with water

Figure 5: Water immersion for temperature stability

3 Summary and Recommendation

The apparent linear elastic limit for the 304 bellows is > 160 psi bellows overpressure, based on the results of these 3 bellows and the apparent linear elastic limit for the 17-7PH bellows is > 450 psi bellows overpressure based on the results of 3 samples. The service/operating pressure of the HEPI system is ~15 psi return + 70 psi maximum differential + ~15 psi supply = ~100 psi. The set point of a pressure relief valve at the pump station would need to be ~20% higher, or ~120psi. Note that a recent fault condition in the LASTI pump station recorded a pressure transient >130psi (the pressure relief valve set point was ~135 psi).

Under normal operating conditions the 304L bellows safety factor is:

- ~160/120 = 1.3, if one uses only a pressure relief valve at the pump station. This is unacceptably low.
- ~160/[(70+15) x 1.2] = 1.6, if one uses a pressure relief valve to the ambient at each chamber (near the actuator). This requires pressure relief valves into "buckets" at each chamber manifold. This safety factor is also unacceptably low, particularly given that the basis is the result of only 3 measurements.

Use of the 17-7ph alloy heat treated TH1050 will increase the normal operating factor to >4.5. The 17-7ph bellows meet all dimensional tolerances. My recommendation is that we use the 17-7ph alloy bellows in the actuators manufactured for the LLO Seismic retrofit.