Advanced LIGO Update to Document 'E970129-01-D': Material, Process, Handling, and Shipping Specification for Welded Diaphragm Bellows

Oct 6, 2009

The following document should be read with the following notes in mind:

1. In this document all approvals describing 'HYTEC' as the contact for approvals shall now be updated to 'LIGO' as the contact for changes and approvals.

2. All references to Senior Flexonics Metal Bellows Division shall now refer to Senior Aerospace.

3. The referenced use of "nitrilite gloves" should now be replaced by the use of latex gloves.

Material, Process, Handling, and Shipping Specification for Welded Diaphragm Bellows

HYTEC, Inc.
August 20, 1997
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This document summarizes HYTEC's requirements for fabrication of welded diaphragm bellows to that interface the LIGO vacuum chambers and support systems. This document applies to both BSC and HAM bellows.

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LIGO PROJECT

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1. Scope

This specification covers aspects important to the fabrication, cleaning, handling, identification, documentation, and shipping of welded diaphragm bellows for the LIGO seismic isolation system.

2. Precedence

In the event of conflict, the order of precedence is
1. The Purchase Order
2. The Drawing
3. This Specification
4. Any Referenced Specification

3. Definitions

HYTEC: Hytec Inc. or other agents procuring products for the LIGO project.
S.F.M.B.: Senior Flexonics Metal Bellows Division.
M.O.S.: Methods Operation Sheet - A shop traveler with detailed work instruction.
U.H.V.: Ultra High Vacuum.
D.I.: Deionized. A process by which metal ions are removed from water reducing its conductivity (the opposite of resistance).
IPA: Isopropyl Alcohol.
Capsule: the welded sub-assembly composed of all the convolutions of the bellows but not including the end fittings and/or flanges.
Chill Ring: Formed or machined, split ring shaped tools, used for maintaining proper spacing and alignment of the capsules during welding.

4. Geometry

Refer to drawing # D972122 for BSC bellows and # D972611 for HAM bellows.

5. Bellows - Functional Requirements

5.1 Environmental

The internal environment of the bellows is Ultra High Vacuum, residual pressure of the order of 10^{-9} torr.
The external environment is atmospheric pressure, room temperature (21±1 ºC), and 0 to 90% relative hunidity.
In addition, bellows shall be able to endure a bake-out at 150 to 160 ºC for approximately 48 hours.

5.2 Mechanical

All bellows manufactured following this specification must be able to endure two thousand (2000) cycles of any combination of axial, transverse, and twist deformations with the amplitudes listed below; all deflections are measured from a "free" length defined on the drawings by the flange face to flange face dimension. In addition, to insure proper functioning of external actuator subsystems, the spring constants (stiffnesses) of the bellows in pure axial and pure transverse directions must not exceed the values listed below.

5.2.1 BSC Bellows

Axial Deflection Transverse Deflection Twist Deflection	+/- 14.0 mm (+/- 0.5512") +/- 20.2 mm (+/- 0.7284") +/- 2.9 mrad (+/- 0.109º)
Axial Spring Constant Transverse Spring Constant Twist Spring Constant	< 9000. N/m (51.4 lb/in) < 65000. N/m (371.2 lb/in) < 400000 N-m/rad (62000 lb.in/°)

Table 1: Mechanical Requirements for BSC bellows[1].

5.2.2 HAM Bellows

Axial Deflection Transverse Deflection Twist Deflection	+/- 11.4 mm (+/- 0.4488") +/- 17.1 mm (+/- 0.5748") +/- 1.6 mrad (+/- 0.035º)
Axial Spring Constant Transverse Spring Constant Twist Spring Constant	< 9000. N/m (51.4 lb/in) < 65000. N/m (371.2 lb/in) < 400000 N-m/rad (62000 lb.in/°)

Table 2: Mechanical Requirements for HAM bellows[1].

In addition to these limits, spring rates shall be consistent from bellows to bellows: the spring rates of any bellows shall not deviate by more than +/- 25% from the mean value
Each bellows shall be tested individually by the vendor to evaluate its axial spring rate. The test shall be performed on the finished assembly and provide a 1-point axial spring rate measurement

5.3 Leakage (BSC and HAM)

All bellows subject to this specification shall be tested by the vendor. The vendor will certify that the bellows assembly does not have leaks greater than 10^{-9} torr.liter/sec of Helium. Equipment and test apparatus used by the vendor must be properly maintained, and documented for calibration and accuracy. Test reports for each bellows will become part of the required travelers (see Section 11).

Any bellows exhibiting a leak greater than 1×10^{-9} torr.liters/sec. shall be repaired, and retested. ASTM E498 Standard Test Methods for Leaks Using the Mass Spectrometer Leak Detector shall be used as a guideline for the leak test.

[1] Based on coarse pitch and roll actuation requirements of +/- 1.5 mrad (verbal conversation with Dennis Coyne, 08/20/97).

Component level leak testing (capsule, fittings) shall be performed without sealing grease if possible. Leak testing fixtures for those components shall be designed for use with dry seals (low durometer Fluoro-elastomer) and leak testing on the First Articles shall be ***attempted*** dry (at a detection level of 10^{-5} torr.liter/sec). The vendor shall submit a leak test procedure for review and approval. In the event that proper sealing could not be achieved with dry seals, the test procedure will be re-negotiated with Hytec and a modified test procedure will be submitted for approval. In the event that the modified test procedure allowed for use of sealing grease, a cleaning process shall be designed to eliminate any trace of such grease on the final product. This cleaning procedure shall be submitted to Hytec for approval at that time.

Leak testing of the completed bellows shall be performed by sealing on the knife edges of the metal flanges at both ends of the bellows. Low durometer Fluoro-elastomer or copper seals are acceptable. ***Absolutely no sealing grease*** may be used for these tests. The vendor shall submit a leak test procedure for review and approval.

6. General Notes

All requirements listed in this document are judged essential to the proper function of the LIGO experiment because of unusually tight requirements on hydrocarbon pollution in the vacuum systems. No substitutions of material types or brand names are allowed unless explicitly approved by HYTEC.

The general philosophy for these requirements is to minimize hydrocarbon contamination of all bellows components at any stage of fabrication because such contamination cannot be subsequently eliminated to the degree required for this project. Welded stainless steel bellows deserve special attention to cleanliness because of their construction. Post-manufacturing chemical cleaning is of negligible value in removing hydrocarbon contamination or particulate matter trapped in the crevices of welded bellows convolutions. Bellows made with improperly handled or poorly cleaned parts may be rendered useless for our purpose.

In Particular:

- At all stages of fabrication, parts are to be considered U.H.V. components and are not to be handled with unprotected hands. Clean U.H.V. quality gloves[2] (Nitrilite™ brand only) must be worn when handling components. Finger cots are not permitted. If the gloves should touch unclean surfaces, such as the face, clothing, tools, bench, chairs, etc. they must be replaced immediately.
- The use of abrasive tools like emery cloth, wire brushes, grinders, etc., is not allowed on any part.
- These parts are to be cleaned and packaged in a specifically prepared for and designated CLEAN ROOM that has a positive pressure, HEPA filtered air ventilation system. The clean room shall be certified Class 1000 or better, and equipped with

[2] Nitrilite™ gloves, mfr. by Ansell Edmont Industrial, Inc., see Appendix A.

full-time hydrocarbon monitoring instrument(s). Hydrocarbon pollution in the air of the clean room shall be maintained below 15 parts per million. This CLEAN ROOM shall be operated and maintained in a manner that will yield parts suitable for U.H.V. service. Personnel responsible for the processing of parts in and maintenance of the CLEAN ROOM shall be familiar with guidelines on clean rooms, exercise good judgment and skill such that the area or parts do not become contaminated. Suitable clean room quality protective clothing, including hooded suits, boots, beard/face masks and gloves must be worn at all times in the CLEAN ROOM.

- All equipment and tooling, *including chill rings (see section 9)*, required for the fabrication and testing of the parts shall be suitable for use in a CLEAN ROOM. All shall be pre-cleaned to remove gross contamination prior to introduction into the CLEAN ROOM then final cleaned with 0.8μm-filtered IPA in the CLEAN ROOM prior to each use.
- All cleaning solvents shall be filtered to a minimum 5μ level prior to use in the CLEAN ROOM.
- The resistance of D.I. water rinse must not be less than 1 MΩ.cm.
- No changes or additions to this specification are allowed without written approval from HYTEC (internal documents used by the vendor to control processes shall be submitted to HYTEC for approval prior to production).
- The use of bubble wrap directly on parts is forbidden. This is due to the fact it's polymers will penetrate into the surface of the metal and cannot be removed during cleaning. Anti-static bubble wrap may be used if the part has first been wrapped in CP-stat[3] sheet or bag or UHV quality Aluminum foil.

7. Raw Materials

All raw materials shall be accompanied with complete physical and chemical certification documents. Copies of these certifications shall be included with the traveler documentation. ***If the vendor prefers to use materials conforming to Specifications other than those listed below or on the drawings, permission to do so must be obtained from HYTEC.***

All attachments to the bellows convolutions, fittings, and flanges must be made from wrought materials such as plate or bar stock of 304 vacuum remelt stainless steel (TFT grade 372, or ESR). Cast material is not allowed. Welded tubing may be used but must conform to an appropriate UHV specification. Fittings made by rolling flat stock into a ring and welding the ends together is not permitted. Parts may not be made from forged material. The surface finish of all fittings and attachments must be 32 micro inches or better or as specified on the drawing(s). All stock surfaces should be machined to remove scale or roughness caused by pickling or rolling. After machining, each piece shall be inspected on all surfaces. Any part which is not 100% sound metal, i.e., free of inclusions, cracks, or any other surface imperfection, including file marks, burrs or sharp edges, shall be rejected.

[3] CP-Stat film, available from Caltex Plastics, see Appendix A.

8. Forming and Machining

All machining shall be performed with sulfur free cutting oils only; approved cutting fluids are listed in Appendix A; deviations from that list must be approved by HYTEC.

Forming operations shall minimize contact with synthetic materials and carbon steel tools if possible.

The use of abrasive cloth or paper, buffing or polishing compounds, or resin bonded grinding wheels is prohibited in finishing any part of the bellows. Any material removal must be accomplished with the use of metal cutting tools.

8.1 Flanges

Flanges are to be machined to the drawings submitted. The use of automatic lathes for machining is strongly recommended. The use of abrasive paper, buffing compounds of grinding wheels is prohibited. All seal details are to be cut with form tools made specifically for that flange design. All dimensions and angles on the form tools must be inspected on an optical comparator before use when new and after reforming.

Form tools are to be changed when seal detail dimensions and/or surface finish approach their tolerance limits. There are three critical dimensions: gasket restraining diameter, knife edge height, and knife edge diameter; these dimensions are to be checked on each flange by the machine operator using specifically designed gauges.

9. Chill Rings and Other Welding Tools

The bellows covered by this specification are assembled with re-useable chill rings and welding tools. Chill rings and other tools that may come in contact with the bellows shall be made of one of the following materials (deviations must be approved by HYTEC):

- Stainless Steel
- 6061 Aluminum
- Nickel plated 6061 Aluminum
- Nickel plated CDA-954 Cast Aluminum
- INCO 600
- Brass

All tools shall be cleaned to remove gross contamination prior to introduction into the CLEAN ROOM then final cleaned with 0.8μm-filtered IPA in the CLEAN ROOM prior to each use.

10. Cleaning Procedure for Diaphragms and Components

This procedure describes the post-forming chemical cleaning of the bellows diaphragms prior to their introduction into the CLEAN ROOM. The procedure is summarized in Figure 1.

Procedure:

***Note**: The following steps and are not required to be performed in the CLEAN ROOM. However, this process shall yield parts sufficiently clean so as to minimize additional cleaning once in the CLEAN ROOM.*

10.1 Pre-clean diaphragms or components in alkaline cleaner (10% Bruhlin 815 HTD detergent or equivalent) for 10 minutes at 140° F with agitation.

10.2 Rinse in room temperature standing D. I. water tank for 5 minutes with agitation.

10.3 Rinse in 120° F counter-current D. I. water tank for 10 minutes with agitation.

10.4 Rinse in second 120° F counter-current D. I. water tank for 20 minutes with agitation.

10.5 Dry in forced hot air dryer with HEPA filtration at 250° F. (Time dependent on configuration)

10.6 Vacuum dry at 190° F and a residual pressure not to exceed 49 torr. (Time dependent on configuration)

10.7 Immerse parts in Electropolish solution 66% Phosphoric acid, 33% Electroglo 300) for 2 minutes at 3 volts at room temperature.

10.8 Rinse in second 120° F counter-current D. I. water tank for 5 minutes with agitation.

10.9 Immerse parts in 300-Series pickling solution for 10 minutes (30% HNO3, 14% Turco Nitrad) at room temperature.

10.10 Rinse in 120° F counter-current D. I. water tank for 10 minutes with agitation.

10.11 Rinse in second 120° F counter-current D. I. water tank for 20 minutes with agitation.

10.12 Dry in forced hot air dryer with HEPA filtration at 250° F. (Time dependent on configuration).

10.13 Visually examine parts for complete removal of oxides, uniform appearance, etc. Excessive etching, pitting or inter-granular attack of the base metal shall be cause for rejection. Repeat steps 10.7 to 10.13 if not acceptable.

10.14 Place diaphragms or components in a clean dry container and cover. Deliver to Clean Room.

10.15 ***Note:** Once parts have been delivered to the CLEAN ROOM, they shall not be removed for any processing other than final packaging in shipping containers unless approved in writing by the cognizant Engineer. Parts shall not be removed from the CLEAN ROOM unless double bagged as described in Section 14.*

10.16 In Clean Room, rinse diaphragms or components in 5μm-filtered hot D. I. water for 5 minutes minimum, keeping parts separated during process.

10.17 Vacuum dry in 0.1μ -filtered dry nitrogen purged oven at 200° F and a residual pressure not to exceed 49 torr.

10.18 Visually inspect at 3.5X (hand glass) with sufficient light for water marks, spotting or chemical residue. Re-clean by repeating steps 10.15 to 10.17 if required.

10.19 Wrap cleaned parts in new UHV quality aluminum foil.

10.20 Place wrapped parts in clean covered containers and store in Clean Room.

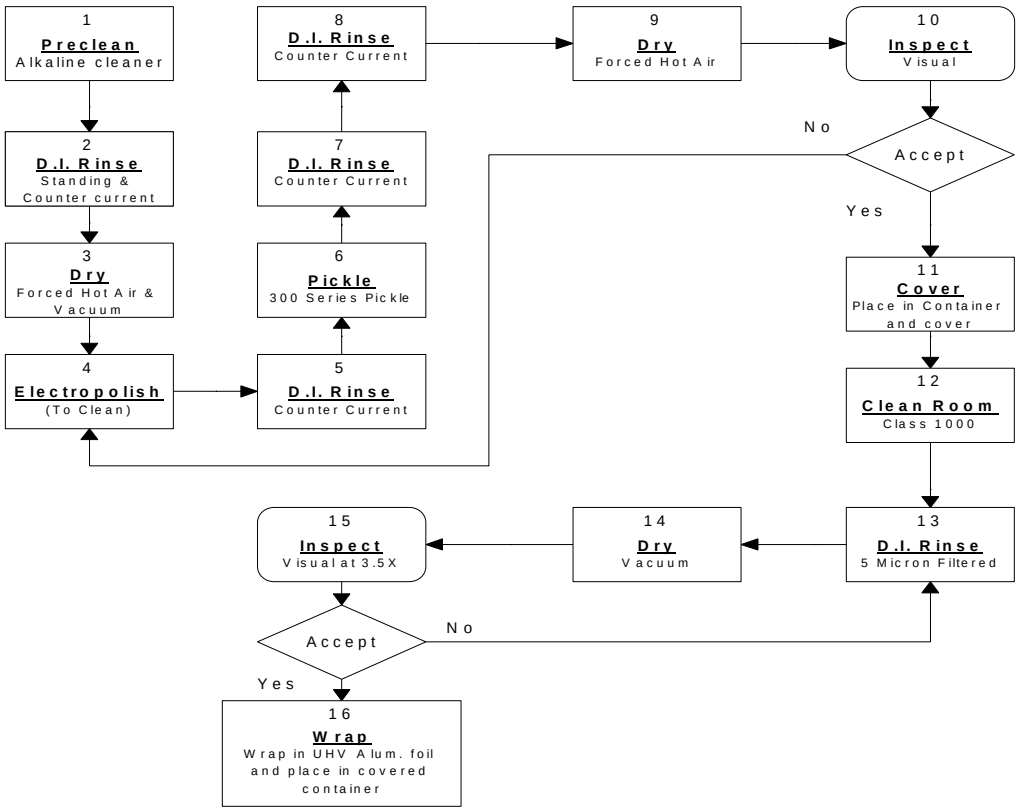

Figure 1: Cleaning procedure for diaphragms and components.

11. Identification and Documentation

Every bellows will be uniquely identified by stamping or engraving the part number (drawing number & revision letter), and a unique serial number (S/N) on the outer edge of the large rotatable flange (see drawings). Each bellows shall be accompanied by a set of travelers identifying the bellows by S/N. The S/N together with the travelers must be sufficient to completely retrace the history of that bellows, from raw materials to final packaging and shipping.

12. Packaging of Final Assemblies for Shipping.

This following describes the procedure to follow for final packaging of the bellows.
Procedure:

***Note**: Steps 12.1 to 12.6 must be performed inside a class 100 section of the clean room.*

12.1 Install 16.5" MDC copper gasket in rotatable flange and secure with (6) stainless steel retaining blocks and hex head screws and washers. Tighten screws only enough to prevent the flange from rotating.

12.2 Wrap the outside of the bellows of each assembly with UHV quality aluminum foil.

12.3 Place each assembly in an anti-static bag fabricated from CP-STAT 100 ESD™ poly sheet as specified on the M.O.S. (CP-STAT 100 ESD™ poly sheet distributed by Caltex Plastics, Inc.)

12.4 Evacuate and back fill the bag with 0.1µ -filtered dry nitrogen .

12.5 Compress bag tightly around the assembly to purge excess nitrogen. Tie wrap the bag for closure.

12.6 Place assembly in second anti-static polyethylene bag, as specified in **6.4.3** above, place "**UHV CLEAN PART…**" and identification labels between bags, remove excess air, purge with dry Nitrogen and heat seal shut, making sure both labels are visible on the rotatable flange end of the assembly.

12.7 Remove double bagged assemblies from clean room, using care to not puncture or cut bags.

12.8 Place double bagged assembly in shipping container with "**UHV CLEAN PART…**" and identification labels facing up. Seal container closed. Attach a label with the LIGO part number (drawing number & revision letter) and serial number to the outside of the container. Attach "This Side Up - Arrow" labels to all (4) sides of container.

12.9 The shipping crates will be designed to insure that the double bags do not get punctured and that the bellows is appropriately supported to avoid mechanical damage during transport. In particular, the bellows shall be supported in a way that essentially eliminates any relative motion between convolutions, flanges, and other parts of the assembly. The design of those shipping crates shall be submitted to HYTEC for approval prior to production.

Appendix A. Handling and Packaging Materials

C.P. Stat material

C.P. Stat 100 ESD sheeting with CFC certification that it passes JPL specifications.
Available from:

Caltex Plastics, Inc.
P.O. Box 58546
2380 E. 51st Street
Vernon, CA 90058
(213) 583-4140
(1 roll 48" wide by 1000 ft long costs approximately $240)

Nitrilite gloves

Nitrilite gloves are 100% Nitrile gloves manufactured by

Ansell Edmont Industrial
Coshocton, OH 43812

They are widely from industrial supply companies.

UHV Quality Aluminum Foil

One source is:
ASTM B-479 Dry Annealed A
Allfoil
4597 Vanepps Rd.,
Brooklyn Ohio 44131, (216)661.0211

Appendix B. Approved Cutting Fluids

Cutting Fluids

Only sulfur-free cutting oils are allowed. The following is a list of explicitly approved cutting fluids. Any deviation from that list requires prior approval from HYTEC.

Aqua Syn 55	Cimcool 5 Star 40	Cimperial #1011
Cutzol EDM 220-30	Dip Kool 868	Dip KUT 819H
Haloform CW-40	Kool Mist #88	No Sul #6871
Rapid Tap	RD2-195	Pearl Kerosene by Chevron Chem Co.
Relton A-9	Rust-Lick G-25-J	Sunnen MAN-852 Honing Oil
Tap Magic	Tapmatic #1	Tapmatic #2
Tool Saver by Do All Corp.	Trim Tap	Vytron Concentrate
Wheelmate #203		