LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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BOSEM
Assembly Specification

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This is an internal working note
of the Advanced LIGO Project, prepared by members of the UK team.

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1 Introduction and Scope

This specification describes the assembly of the **BOSEM, D060218**, used in the Advanced LIGO suspensions. The coilformer main assembly comprises of two sub-assemblies; the **PD assembly, D060217** and the **IRLED assembly, D060216**, which combine to form the optical sensor. The coilformer clamp and adjustment assemblies are also discussed. Finally, instructions for the fabrication of the **Pigtail Harness assembly, D070156**, are provided.

1.1 Version History

Rev. 00 - Initial release. May 2007 (SMA)

Rev. 01 - Material change all PFA-440HP parts switch to PEEK 450G. January 2008 (SMA)

Rev. 02 - Updated to address feedback generated during FRR / FDR review. April 2008 (SMA)

1.2 Acronym List

ALUK	Advanced LIGO UK
ATE	Automated Test Equipment
BOSEM	Birmingham Optical Sensor and Electro-Magnetic actuator
DVM	Digital Volt/Multi-meter
ESD	Electrostatic Discharge
ID	Inner Diameter
IRLED	Infrared Light Emitting Diode
LIGO	Laser Interferometer Gravitational Wave Observatory
OD	Outside Diameter
OSEM	Optical Shadow sensor and Electro-Magnetic actuator
PD	Photodiode
PEEK	Polyetheretherketone
PFA	Perfluoroalkoxy fluoropolymer (Du Pont)
SUS	Suspensions Working Group
TBC	To Be Confirmed
TBD	To Be Determined
UHV	Ultra High Vacuum
UIM	Upper Intermediate Mass
UM	Upper Mass

1.3 References

(1) E030350-A, D. Coyne, C. Torrie - “Drawing Requirements”.

(2) T040111-00, M. Gerfen, L. Jones, C. Torrie - “Galling Tendencies and Particles Produced by Ultra Clean Screw Threads”.

(3) E960022-B-E, LIGO Systems Engineering - “LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures”.

(4) T050111-03-K, S. M. Aston - “BOSEM Design Document & Test Report”.

(5) E030084-02-D, J. Romie - “Hybrid OSEM Assembly Specification”.

(6) T040127-00-D, R. Taylor - “Cleaning procedure for magnet wire with ML/HML insulation”.

(7) T070107-04-K, D. Lodhia, S. M. Aston - "BOSEM Test Specification”.

2 Parts List

See the parts list for the following top level assembly:-

D060218 – BOSEM assembly

Under which is the parts list for the following sub-assemblies:-

D060216 – IRLED assembly

D060217 – PD assembly

D070156 – Pigtail Harness assembly

3 Part Fabrication

3.1 Fabrication Specification

For all fabricated parts, the detailed drawings provide the specification required for part manufacture. Drawings generated have been detailed and dimensioned in accordance with reference [1]. These drawings also include instructions to vendors regarding use of machining fluids and locations for part labeling.

It should also be noted that for all parts, tapped holes for stainless-steel screw fixings are oversized in accordance with the recommendations made in reference [2].

3.2 General Inspection

When parts are provided by the vendor they are inspected for dimensional acceptance. Confirm that radii and other features comply with callouts shown on the drawings. Ensure that all burrs / frays and sharp edges have been completely removed. Finally, check the integrity of the oversized threads.

Reject any parts which do not meet the specification.

3.3 Part Identification

Part and serial number identification will be accomplished as described in reference [1]. Part labeling is to be present for all large aluminum parts and will be omitted for parts deemed too small. The flexi-circuit part will also be uniquely identifiable. Table 1 provides a list of parts that, due to their size and / or material selection, do not comply with having a part or serial number visible.

Part Number	Description	Material
D060109	Adjuster Shaft	Titanium
D060110	Adjuster Nut	PEEK 450G
D060117	PD Sleeve	Macor
D060116	IRLED Sleeve	Macor
D060115	IRLED Lens Retainer	Phosphor Bronze
D060114	PD Retainer	PEEK 450G
D060113	IRLED Retainer	PEEK 450G

Table 1. List of OSEM parts with no visible identification or serial numbers

3.4 Pre-assembly Tasks

Prior to cleaning and assembly some parts will be required to go through additional pre-assembly processes. These are detailed as follows:-

Task 1. As supplied (off-the-shelf), the leads of the PD and IRLED packages are too long to be accommodated within the sensor assemblies. For this reason, they can be trimmed to length with a wire cutting tool using the dimensions given below:-

- PD, both anode and cathode leads trimmed to 0.354” [9.0mm] long.
- IRLED, both anode and cathode leads trimmed to 0.197” [5.0mm] long.

Task 2. The protruding ‘tag’ on the OD of each of the sensor devices discussed above, should not exceed 0.143” [3.6mm] from the centre of the device. *Note that, the ‘tag’ is required for locating and orientating the device and should not be removed completely.*

Task 3. The flexi-circuits incorporate a visible part number within the routing of the circuit. There is also the provision for a unique serial number, but this must be scribed manually. A clear solder pad is available, below the part number, onto which the serial number can be marked (see figure 1). *Note that, the marking process will not add any contamination to the part.*

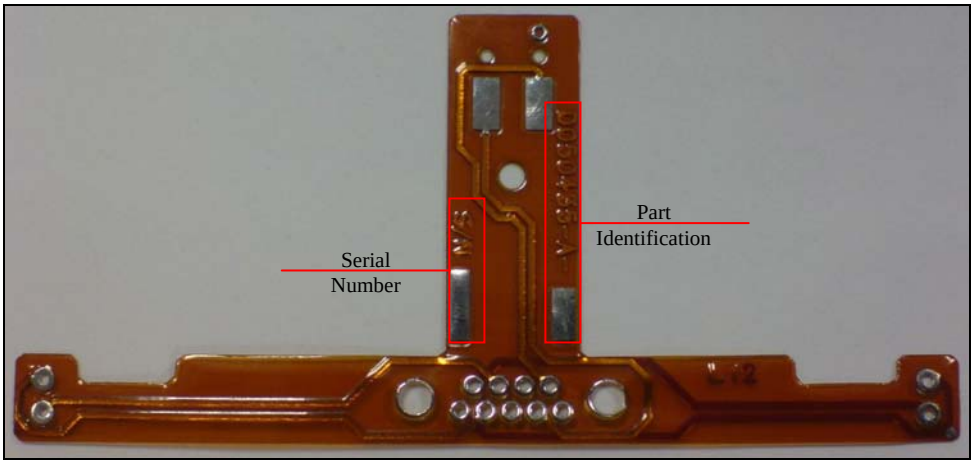

Figure 1. Flexi-circuit part identification and serial number

Task 4. The solder pins on the 9W right-angled micro-D connector are pre-tinned in a solder bath. *This is to aid later soldering tasks.*

All assembly steps described in the following sections now take place within clean room facilities, with personnel dressed in clean room garb, undertaking UHV component handing requirements and any necessary ESD precautions, as described in reference [3].

3.5 Cleaning Methods

Cleaning and baking procedures will be carried out in accordance with reference [3]. All cleaning steps shall be followed for all materials in use, but with the following exception:-

- There is a deviation from the procedure outlined for the Hybrid OSEM Assembly Specification (reference [5], section 4.5). The hot bake on the partly assembled OSEM (i.e. coil wound onto coilformer) will be omitted. Instead, an equivalent hot bake will be carried out on the complete BOSEM assembly (see section 5).

n.b. It will also be necessary to carry out a pre-cleaning process on the coil winding wire, as supplied by the manufacturer. The aim of the procedure is to remove any trace contaminants (e.g. paraffin, mineral oil etc), prior to winding the coils. Details of this process can be found in reference [6].

Tooling and fixtures which may come into contact with the in-vacuum deliverables during the assembly or transportation are to be cleaned and baked as LIGO “Class B” material. See reference [3], Section 3 of Appendix A for the correct processing procedure. For example, the coil winding machine (discussed later in Section 4.2.1) is required to be cleaned as a “Class B” item, prior to being used in the clean-room facilities.

4 BOSEM Assembly

4.1 Sensor Assemblies

This section covers the assembly of the two individual sensor sub-assemblies, the **PD assembly, D060217** and the **IRLED assembly, D060216**.

4.1.1 PD Assembly

Table 2 details parts required for this stage of the assembly.

Part Number	Description	Material
D060112	PD Carrier	Aluminum 6061 (6082)
D060117	PD Sleeve	Macor
D060114	PD Retainer	PEEK 450G
BPX65	PD	*n/a*

Table 2. Required parts for PD assembly

Insert the PD into the bore of the sleeve. Line up the collar and tab on the PD to the recess and slot on the sleeve. Then line up the flat on the sleeve to the drilled hole in the carrier, and push the sleeve and PD assembly into the barrel of the carrier. Once in place, push the setting pin through the hole in the carrier wall, and leave the pin in place. Insert the pins of the retainer screw tool into the drilled holes in the retainer and screw the retainer into the carrier until the end surface of the retainer is flush with the surface of the carrier. This will clamp the PD and sleeve in place, but take care to not over tighten. Finally, remove the pin from the carrier wall and retainer screw tool. See figure 2 for a section through the completed assembly.

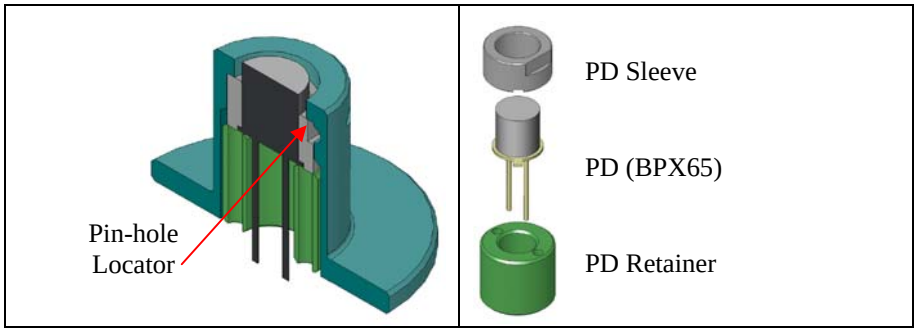

Figure 2. Section view through the assembled PD carrier and part explosion

4.1.2 IRLED Assembly

Table 3 details parts required for this stage of the assembly.

Part Number	Description	Material
D060111	IRLED Carrier	Aluminum 6061 (6082)
D060116	IRLED Sleeve	Macor
D060113	IRLED Retainer	PEEK 450G
D060115	IRLED Lens Retainer	Phosphor Bronze
OP232	IRLED	*n/a*
08PQ06	Collimating Lens	Glass

Table 3. Required parts for IRLED assembly

Ensure that the collimating lens is handled with care; avoid direct contact with the optical surfaces. In the event of deposition the lens surface, clean as appropriate. The collimating lens is inserted into the ID of the carrier, with the convex surface facing down, against the mask aperture (i.e. with the lens planar surface facing up). Use tweezers to locate the collimating lens within the carrier's internal aperture. Ensure that the lens does not change its orientation whilst traveling to the end of the cylinder. Next, insert the lens retainer spring into the same ID of the carrier using tweezers. Conduct a visual inspection to ensure that the vent hole on the carrier wall is clear and is not obscured by the lens retainer spring. If so, then rotate the lens retainer until the vent hole appears clear (see figure 3).

Insert the IRLED into the bore of the sleeve, and position the tab of the IRLED package to be coincident with the recess on the sleeve. Insert the sleeve and IRLED assembly into the carrier bore, and ensure that the flat of the sleeve is in line with the setting pin hole in the carrier wall. Once in place, push the setting pin through the hole in the carrier wall, leaving the pin in place. Insert the pins of the retainer screw tool into the drilled holes in the retainer and screw the retainer into the carrier until the end surface of the retainer is flush with the surface of the carrier. This will clamp the IRLED and sleeve in place, but take care to not over tighten. Finally, remove the pin from the carrier wall and retainer screw tool. See figure 3 for a section through the completed assembly.

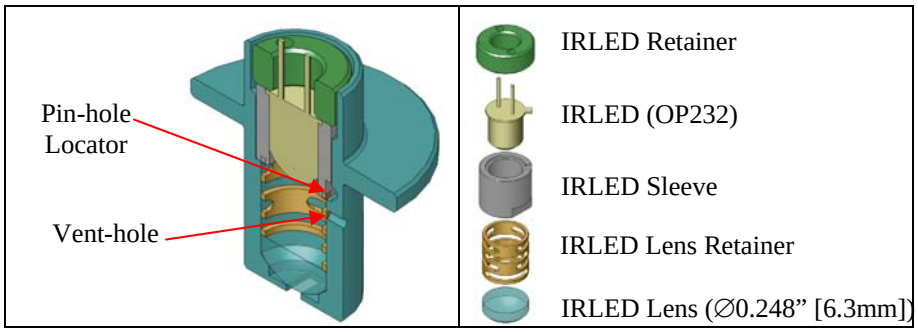

Figure 3. Section view through the assembled IRLED carrier and part explosion

4.2 Coilformer Assembly

This section covers the winding of the actuator coil onto the coilformer and incorporates the installation of the interconnection components.

4.2.1 Coil Winding

Table 4 details parts required for this stage of the assembly.

Part Number	Description	Material
D060106	Coilformer	Aluminum 6061 (6082)
D060215	Windoff Spacer (tooling)	PFA 440HP
QML32	MWS Coil Winding Wire	Cu - Polyimide

Table 4. Required parts for actuator coil assembly

Prepare the coil winding machine by winding the handle (on the right-hand side) clockwise (observing the machine from the right), until the scribed line on the back of the shaft (on the left-hand side of the machine) is just visible. The counter should read zero, and the winding handle should be at its lowest position. See figure 4a.

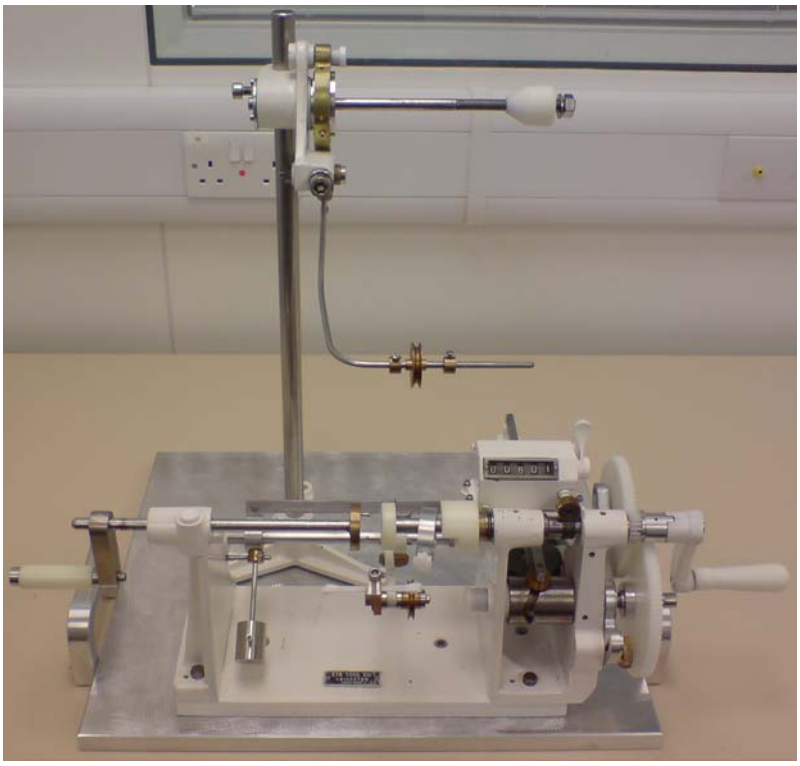

Figure 4a. Coil winding machine

The coilformer is inserted onto the PFA 440HP jig located on the main winding shaft of the coil winding machine. The coil winding wire can be threaded from the spool, through the machine and around to the rear of the slot in the coilformer. This is designated the “start” of the coil winding. An aluminum clamp is fitted around the coilformer to constrain the start of the coil winding wire. Ensure that the winding wire is fed through the cleaning wipes before being wound onto the coilformer.

Wind the right-hand side handle 800 times clockwise (i.e. over the top and away from the operator). At regular intervals (e.g. every 100 turns) ensure that the cleaning wipes remain heavily soaked with cleaning solvent. In addition, carry-out an inspection of the condition of the wipes and replace if there is contamination evident.

When the 800 turns are complete, cut the wire and loop the end through the windoff spacer. Unclamp the starting end of the wire and loop this end into the remaining hole in the windoff spacer. Pull both ends of the wires to remove any slack, whilst positioning the windoff spacer onto the central part of the flat on the coil former. Making sure the two ends of the wires are taut, trim both ends until each are 0.32”-0.39” [8–10mm] long. Using rotary blade strippers remove the last 0.16” [4mm] of insulation from both the start & finish ends of the coil winding. See figure 4b for a view of this assembly.

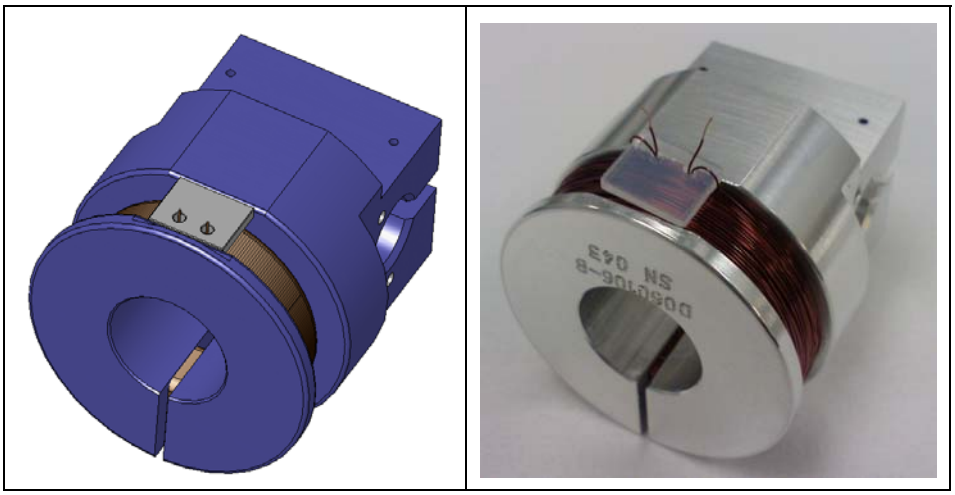

Figure 4b. Coilformer and actuator coil assembly

4.2.2 Coil Winding Inspection

Conduct a visual inspection of the coils. Check that the wires have been laid down uniformly. Using a DVM, measure the coil resistance and coil-to-body resistance. Measure the coil-to-body resistance by attaching one probe to the end of the coil wire whilst putting the other probe up against the body of the coilformer. Check the coil-to-body resistance again using the start of the coil winding. Finally, note down these results as outlined in section 2.1 of reference [7].

If a number of units are to be assembled in a batch, then they should all be assembled (and inspected) to this stage, before proceeding further.

4.2.3 Interconnections

Table 5 details parts required for this stage of the assembly.

Part Number	Description	Material
D060106	Coilformer	Aluminum 6061 (6082)
D050435	Flexi-circuit	Cu - Kapton
Connector (GlenAir)	9W male right-angle micro-D	*n/a*

Table 5. Required parts for interconnection assembly

Locate the connector over the two fixing holes on the top flat surface of the coilformer. Position the flexi-circuit on-top of the connector, ensuring that layer one (denoted L1 on the part) is facing up, and L2 is facing the coilformer. The identification information available on the flexi-circuit part

should be easily legible, if the correct orientation has been adopted. Secure the connector and flexi-circuit in place using two 2-56 UNC × ½" socket cap screws. Figure 5 provides a view of this assembly.

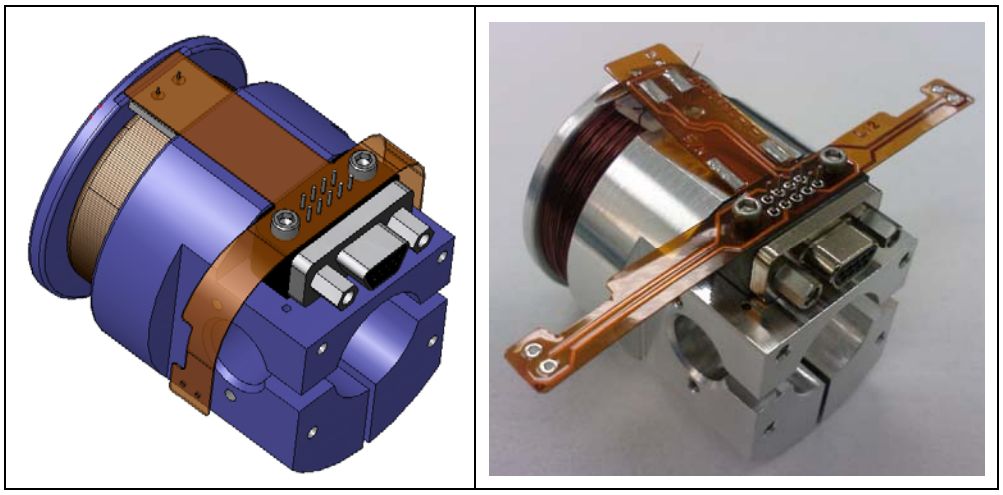

Figure 5. Coilformer and interconnection assembly

4.3 Final Assembly

This section details the integration of the PD & IRLED sensor sub-assemblies into the main coilformer and the final soldering task.

4.3.1 Sensor Integration

Table 6 details parts required for this stage of the assembly.

Part Number	Description
D060106	Coilformer
D060216	IRLED assembly
D060217	PD assembly

Table 6. Required parts for sensor integration into coilformer

Looking at the rear of the BOSEM (i.e. with the coil winding furthest away from you), the PD assembly is inserted into the right-hand side of the aperture, and the IRLED assembly is inserted into the left-hand side of the aperture (as can be seen in figure 6). Ensure that the two screw holes in the rim of the sensor carriers are lined up with the screw holes in the side of the coilformer

aperture. Insert two 2-56 UNC × ¼" socket cap screws into each of the sensor carriers to secure them to the coilformer. Ensure these are screws fixings are finger-tight.

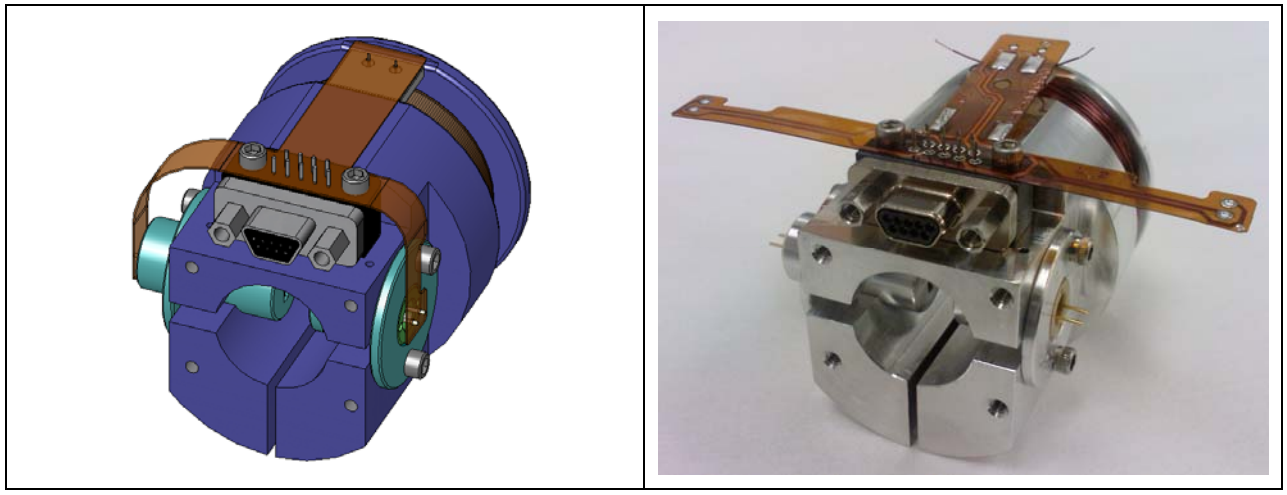

Figure 6. Coilformer and sensor assembly

4.3.2 Sensor Inspection

Conduct a visual inspection to ensure that the slotted mask in the end of the IRLED assembly is orientated vertically (runs from the top-to-bottom of the coilformer). Also, inspect that the leads on the sensor components are orientated horizontally for both the PD & IRLED assemblies (see figure 6).

4.3.3 Soldering

This task is left until last and should be conducted in a dedicated and separately filtered environment to the coil-winding and other assembly tasks. For all the following soldering operations use the minimum amount of solder.

Task 1. The windoff spacer can be removed and the unsecured end of the flexi-circuit can now be raised to allow the wires from the coil winding to be fed through from the underside. The start and end coil windings can be routed via through-holes in the flexi-circuit to solder pad locations. The stripped coil start and end wires can be soldered down to the appropriate solder pad on the top side (L1) of the flexi-circuit. Note, that the 'start' pad is denoted on the flexi-circuit by a small dot/hole above the pad.

Task 2. Solder all 9 pins of the micro-D connector to the flexi-circuit solder pads.

Task 3. Finally, wrap the extended sections of the flexi-circuit around the body of the coilformer. Then solder the leads of the sensor components down onto the flexi-circuit to secure in place.

Once tasks 1-3 are complete, carefully use a small hard-bristled brush dipped in isopropyl alcohol to brush over the soldered joints to remove any flux residue. This step should remove most of the flux. Use another beaker of clean isopropyl alcohol for a final cleaning.

4.3.4 Soldering Inspection

Inspect each solder joint under a stereo microscope to ensure no undesirable joints (e.g. dry joints) are present. Conduct any solder joint re-working (and cleaning) as necessary.

4.4 Clamp and Adjustment Assembly (Optional)

This section details the assembly of the clamp and adjustment assembly. It should be noted that this may not be required for all BOSEM mounting locations and so can be removed from a complete assembly (by reversing the procedure described here). However, all BOSEMs are supplied complete i.e. with the clamp and adjustment assembly fitted.

Table 7 details parts required for this stage of the assembly.

Part Number	Description	Material
D060106	Coilformer	Aluminum 6061 (6082)
D060107	Coilformer Backplate	Aluminum 6061 (6082)
D060108	Coilformer Clamp	Aluminum 6061 (6082)
D060109 (2 off)	Adjuster Shaft	Titanium
D060110 (2 off)	Adjuster Nut	PEEK 450G

Table 7. Required parts for coilformer clamp and adjustment assembly

Locate the coilformer onto the backplate, ensuring that the slot in the coil former is coincident with the slot in the backplate. Orientate the backplate so that when looking at the back of the coilformer, the shoulders for the adjuster nuts are located at the bottom left and top right. Using four 2-56 UNC × 5/16” socket cap screws, secure the backplate to the coil former (see figure 7a).

Insert the two adjuster nuts into the shoulders of the backplate, ensuring that the hexagonal head is facing towards the back of the BOSEM (see figure 7a).

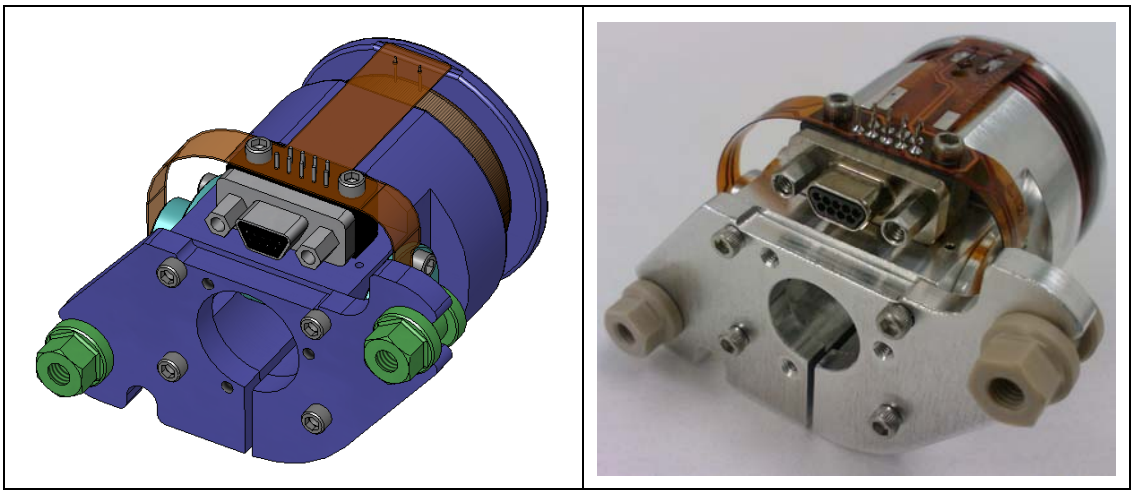

Figure 7a. Coilformer and backplate assembly

Take the two adjuster shafts and screw the side with the 'short' thread into the tapped holes in the coilformer clamp. Ensure that these are screwed into the side of the coilformer clamp with the extruded features that support the coilformer (see Figure 7b). The adjuster shafts can then be tightened by means of the hexagonal head, using a 9/32" spanner.

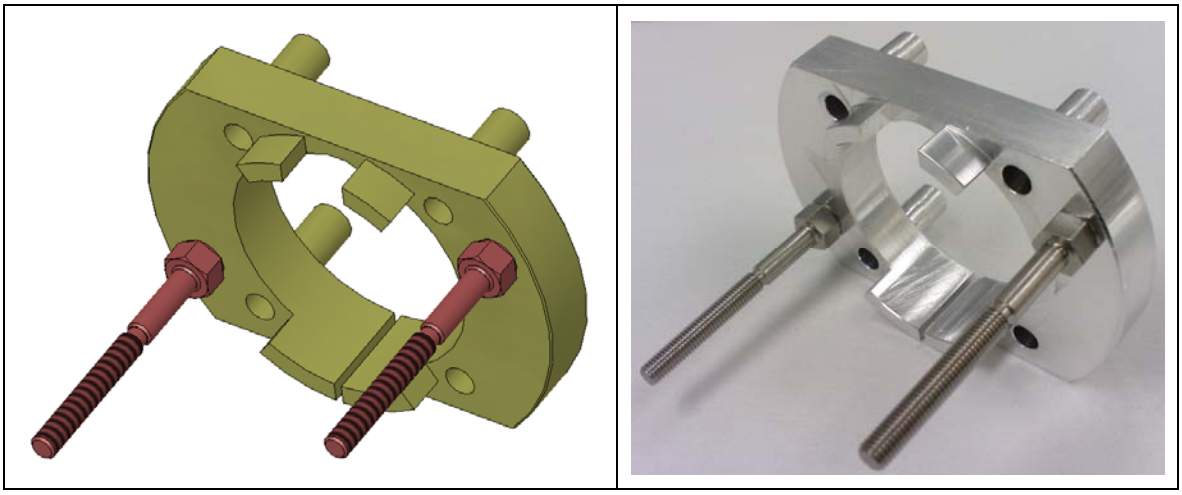

Figure 7b. Clamp assembly

Finally, the coilformer and backplate assembly can be loaded onto the threaded shafts of the clamp assembly and into guide features within the clamp. Ensure that the slots in the coilformer and clamp are coincident. Use a 9/32" socket spanner to wind the adjuster nuts down along the adjuster shafts, alternating a few turns on each side. Continue until the adjuster nuts are approximately halfway up the adjustment shaft threads (i.e. until the same amount of thread is visible on either side of the adjuster nut). The fully completed BOSEM assembly should appear as shown in figure 8.

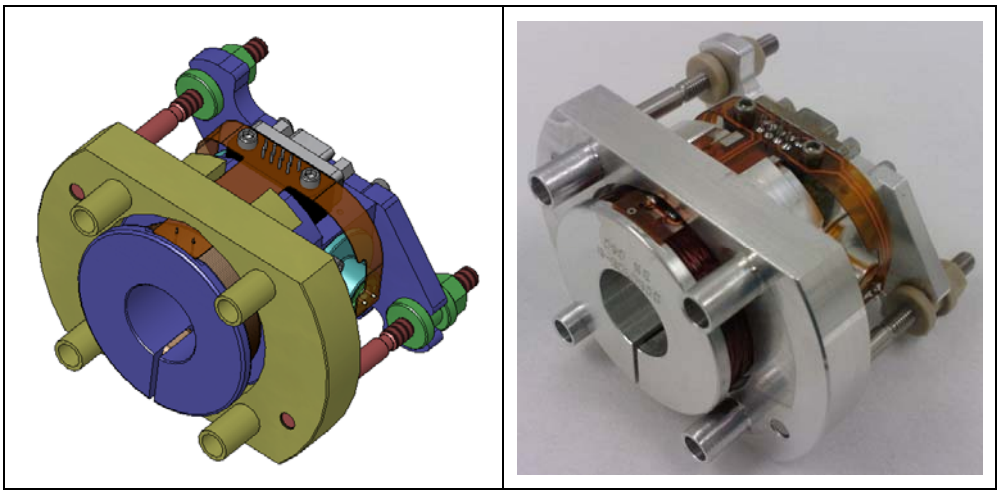

Figure 8. Completed BOSEM assembly

4.5 BOSEM Testing

BOSEM test data can now be taken and logged using the ATE as described in section 2.2 of reference [7].

4.6 Pigtail Harness Assembly

This section of the assembly specification covers the fabrication and assembly instructions for the pigtail harnesses.

Table 8 details parts required for this stage of the assembly.

Part Number	Description	Material
Connector (GlenAir)	9W female straight micro-D	*n/a*
Connector (GlenAir)	9W micro-D backshell	*n/a*
Connector (GlenAir)	25W male straight micro-D	*n/a*
Connector (GlenAir)	25W female straight micro-D	*n/a*
Connector (GlenAir)	25W micro-D backshell	*n/a*
Connector (Accu-Glass)	25W male straight sub-D	*n/a*
Pigtail (Cooner)	Ultra miniature flexible wire	Cu - Teflon insulated
Shield (Cooner)	Tubular braid	Cu
Shield Termination (Band-It)	Micro bands	Stainless steel

Table 8. Required parts for pigtail harness assembly

n.b. the list given in Table 8 refers to all the parts required to fabricate a UIM harness. Stages such as the UM will not require the additional 25W micro-D connection in the harness.

For all of the following soldering operations use the minimum amount of solder. Also, clean off solder flux.

Task 1. Neatly strip, tin and solder 6 pigtail wires to the back of a 9W female straight micro-D connector. Then attach a 9W micro-D backshell. Repeat this task 4 times (given there are 4 BOSEMs per harness).

Task 2. Twist each pair of wires about 5 twists per inch. Loosely braid the three pairs to the end. Ensure the pairs do not untwist while braiding. Cable lengths are as shown in **D070156**.

Task 3. If required, the harness can be cut to insert the additional 25W male and female micro-D connectors and backshells. See **D070156** for details.

Task 4. Where necessary, an overall braid can be added to provide extra screening for the harness. The braid can be terminated at the backshell of a connector using a micro band and the Band-It termination tool. See **D070156** for details.

Task 5. Finally, strip, tin and solder the pigtail onto the 25W male sub-D connector. See **D070156** for details.

Tasks 1-5 need to be repeated for each harness fabricated.

5 Final Clean and Bake

As described in reference [3], ultrasonic clean the complete BOSEM / harness assemblies in methanol for 10 minutes. Then soak in isopropyl alcohol for 10 minutes, agitating regularly. Finally, bake in-vacuum at 120^0C for 48 hours.