LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

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BOSEM
Assembly Specification

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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.

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)

Rev. 03 -

Rev. 04 - Changed the wire cleaning process & references to match AOSEM procedure. Added IR LED screening step and reference to screening document. Added minor modifications to coil winding after upgrade of winding machine. Updated final clean and bake.

Rev. 05 - Removed unused references. Updated IRLED type number. Removed section 4.6 (Pigtail harness assy) as it is beyond the scope of this document (and is documented elsewhere). Added clarification to section 4.1.2 (IRLED assembly) for orientation of the IRLED. Added steps required to identify BOSEMs fitted with lowest noise LEDs (for use in critical locations). Added additional sample noise tests on finished devices (section 4.5) as outlined in RODA. Soldering of the connector onto the flexi circuit is now performed as a pre-assembly task to allow more thorough cleaning to prevent solder residues being trapped between the flexi and the connector body. Added recommended torques for fixings.

Rev. 06 - Added check to ensure that the PD is inserted properly in its carrier, and is aligned correctly.

Rev. 07 – Added corrections and clarifications to the coil winding process to ensure parts are wound in the same sense as Adv LIGO BOSEMs. Also added note on cropping pins on uD connector. Added to, and clarified pre-assembly tasks. Added Bake temperatures to sec 3.5, and note on cleaning connectors in acetone.

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-v25, 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) E0900168-v7-R.Abbot – “AOSEM Assembly specification”.

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

(8) T1900596, D.Hoyland, J Bryant – BOSEM IR LED Screening Procedure

(9) M1900038 RODA BOSEM replacement IRLED.

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

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. The IRLEDs require burn in prior to use. This process aims to remove devices which fail early or whose output intensity degrades quickly from the BOSEM assembly flow. The process is detailed in ref [8].

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 IRLEDs require selection screening prior to use. This is to ensure that devices used in production exhibit the required noise characteristics, and that their output intensities produce photocurrents which match the photocurrent range of BOSEM units currently in operation. The screening process is contained in ref [8].

Note that IRLED devices may be graded into 'normal' and 'enhanced low noise' bins. When assembling a BOSEM with an 'enhanced low noise' device, the finished unit will require identification as an enhanced low noise unit (section 4.5).

Task 4. 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 5. The Macor sleeves for the IRLED and Photodiode must be individually reamed to provide a 'snug' fit to the devices, ensuring they locate precisely and repeatably when assembled into the LED and PD mounts.

Task 6. The flexi-circuits incorporate a visible part number within the routing of the circuit. There is also the provision for a unique serial number: A clear solder pad is available below the part number, onto which the serial number can be scribed if required (see figure 1). *Note that, the marking process will not add any contamination to the part.*

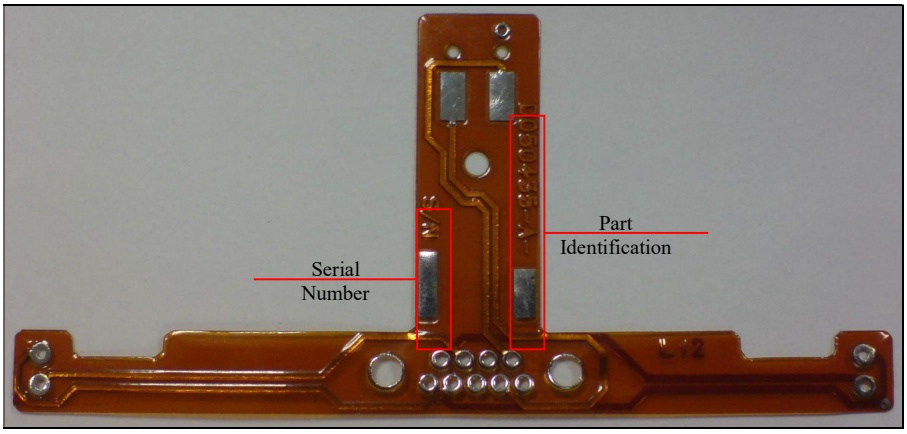

Figure 1. Flexi-circuit part identification and serial number

Task 7. The Flexi circuit and micro D Connector should be cleaned as described or referenced in section 3.5 below (no bake required at this stage). This ensures that contaminants are not trapped under the connector when it is soldered to the flexi circuit.

The solder pins on the 9W right-angled micro-D connector should be pre-tinned (if required) in a solder bath. Then, using a (clean) Coil Former as an assembly jig, locate the connector over the two fixing holes on the top flat surface of the Coil Former. 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 Coil Former body. Temporarily secure the connector and flexi-circuit in place using two 2-56 UNC × ½" socket cap screws, and solder all pins on the connector. Release the screws and remove connector and flexi circuit. Crop the connector pins just above the solder joint, to ensure the pins cannot be bent and short together. Carefully use a small hard-bristled brush dipped in isopropyl alcohol to brush over the soldered joints to remove any flux residue (the assembly will then undergo a full clean and bake in Task 8 below).

Task 8. **All** parts including the Flexi/connector subassembly and the winding wire, should be cleaned and vacuum baked as described or referenced in section 3.5.

Task 9. All tools, jigs and fixtures which come into contact with the BOSEM during assembly, test or transportation must also be cleaned as described or referenced in section 3.5.

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

All parts must be Cleaned and baked in accordance with reference [3]. All cleaning steps shall be followed for all materials in use, with the following exceptions:

i) Connector wash in acetone should be 5 minute only.

ii) Coil winding wire will be cleaned as described below. This is to remove any trace contaminants (eg paraffin, mineral oil, etc.) *prior* to winding the coils:

1) Clean several take up-spools in isopropyl alcohol

2) Clean the wire by passing it from the spool, through a bath of Toluene (wiping thro clean room wipe submerged in the toluene) onto a clean take-up spool.

3) Allow to dry for 24Hrs

4) Repeat steps 2 and 3 as required using an Isopropyl Alcohol bath.

(The requirement for step 4 will be verified by passing the wire through a wipe on the clean take-up side of the toluene bath (step2) and inspecting for residue. If residue is found, then step 4 will be added, with similar inspection to ensure wire is thoroughly cleaned)

5) Vacuum bake the wire on the clean take up spools in accordance with reference [3].

Caution: *Toluene is harmful. Do not inhale or allow it to contact with skin. Wear gloves, protective over-garment and eye protection. Perform cleaning in a fume cupboard.*

Baking temperatures are provided below for reference:

Complete BOSEM: 120C

Kapton circuits and soldered components: 120C

Phosphor bronze springs: DO NOT BAKE

Aluminium, Titanium, Kapton insulated copper wire: 150C

Peek, Stainless Steel, Glass, Macor: 200C

Tooling and fixtures which may come into contact with the in-vacuum deliverables during the assembly or transportation are to be cleaned per 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

Record the device serial number on the batch record sheet (traveler). Note on record sheet the LED type (normal or enhanced noise), and complete record sheet as required during assembly.

The BOSEM assembly uses 2-56 UNC fixings, they should be torqued to 0.21Nm.

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. To check alignment of the photodiode, insert the assembly into a coil former, aligning the fixing screw holes. Look at the photodiode front face thro the opposite side of the coil former (where the IRLED carrier assembly fits). The die of the photodiode should sit 'square on', presenting a flat edge to the flag when it is inserted, as shown below

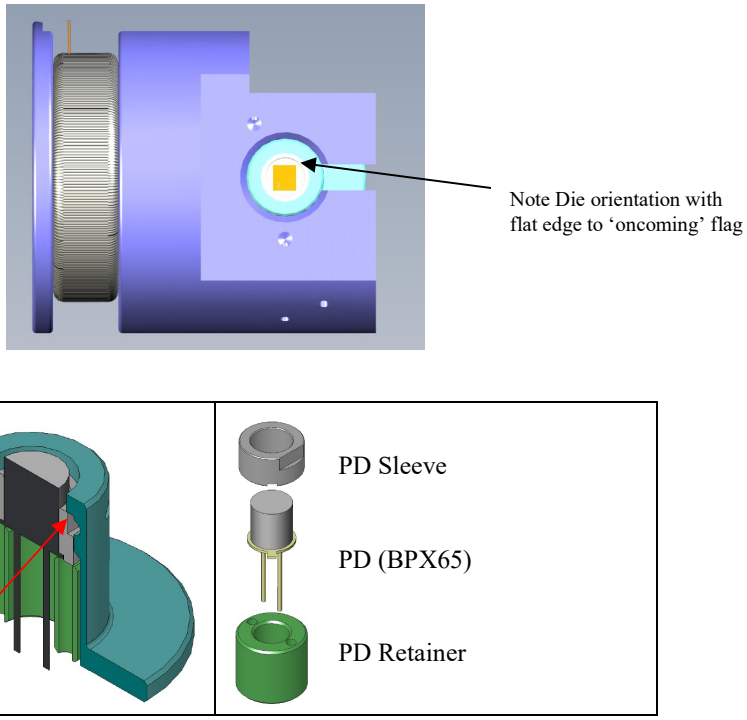

Figure 2. View showing PD die when correctly mounted in PD Carrier, and section view through the assembled PD carrier with part explosion

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
OP132	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. Stack the Sleeve, Lens Retailer and Lens vertically (The collimating lens positioned so that the convex surface fits against the mask aperture) and carefully lower the Carrier over them to locate in place.

Ensure that:

1. The flat of the sleeve is in line with the setting pin hole in the carrier wall
2. The lens does not change its orientation whilst traveling to the end of the cylinder.
3. 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).

Once in place, push the setting pin through the hole in the carrier wall, and leave in place. 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. ***Note 1***. 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 setting pin from the carrier wall and the retainer screw tool. See figure 3 for a section through the completed assembly.

Note 1 The IRLED sleeve (D060116 rev D) has 2 adjacent recesses for the IRLED tab. This allows different device types to be fitted as necessary (eg TSTS7100, OP132). For OP132 ensure the device is located such that the tab sits in the slot nearest the back (connector) end of the BOSEM. (The tab on the OP132 identifies the CATHODE)

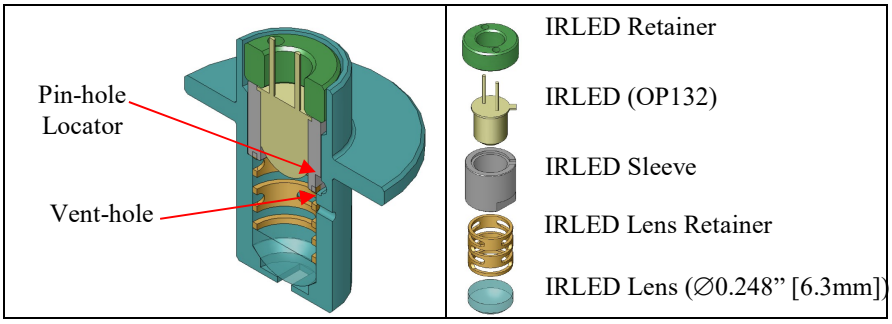

Figure 3. Section view through the assembled IRLED carrier and part explosion

4.2 Coil former 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	Wind-off 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 BOSEM anti-clockwise (observing the machine from the right hand side) until the traversing mechanism is to the far right end of its travel (so the coil starts winding cleanly). Reset the counter to zero.

Figure 4a. Coil winding machine

The coil former is inserted onto the bushing on the main winding shaft of the coil winding machine, locating in the PTFE jig. 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. Secure the coil former with the PTFE retainer (see figure 4a). Wind the coil by turning ***anticlockwise*** (as viewed from the ***right hand side*** of the machine). The counter should count ***upwards*** from zero. The correct winding sense can be verified from Fig 4c below.

When the 800 turns are complete, cut the wire and loop the end through the wind-off spacer. Unclamp the starting end of the wire and loop this end into the remaining hole in the wind-off spacer. Pull both ends of the wires to remove any slack, whilst positioning the wind-off 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.

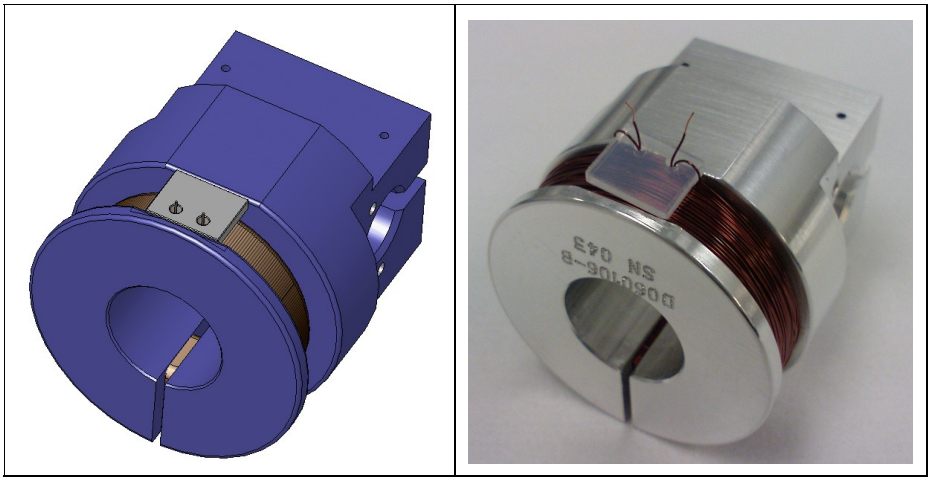

Figure 4b. Coilformer and actuator coil assembly

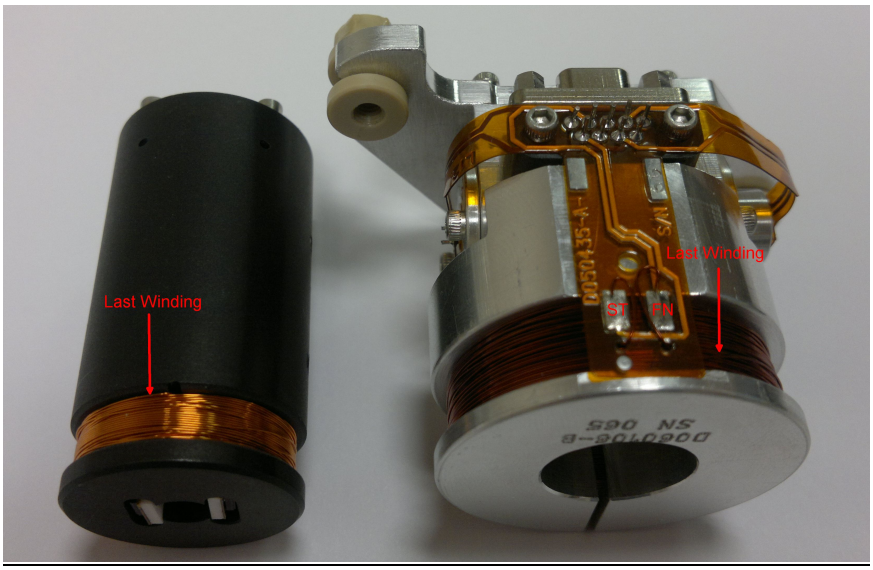

Figure 4c Coil winding sense of BOSEM compared to AOSEM

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 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 with flexi circuit over the two fixing holes on the top flat surface of the coilformer. 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.

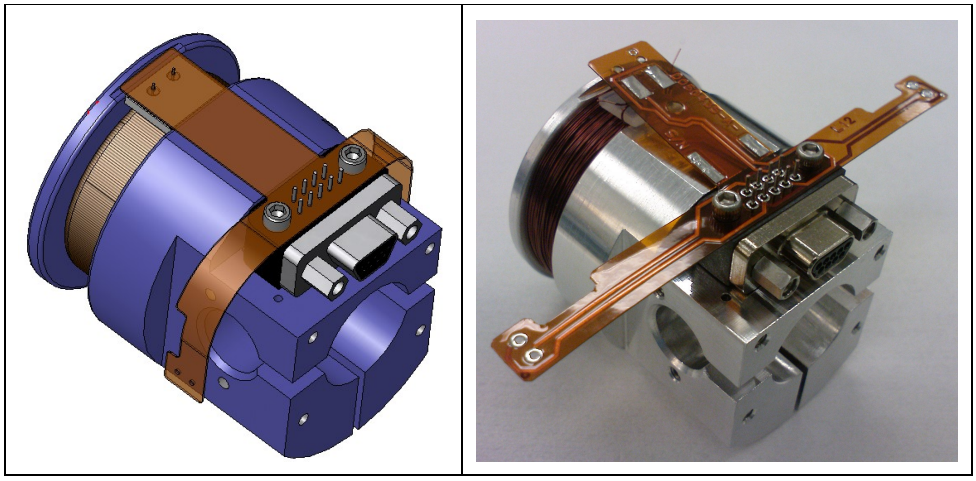

Figure 5. Coilformer and interconnection assembly

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.

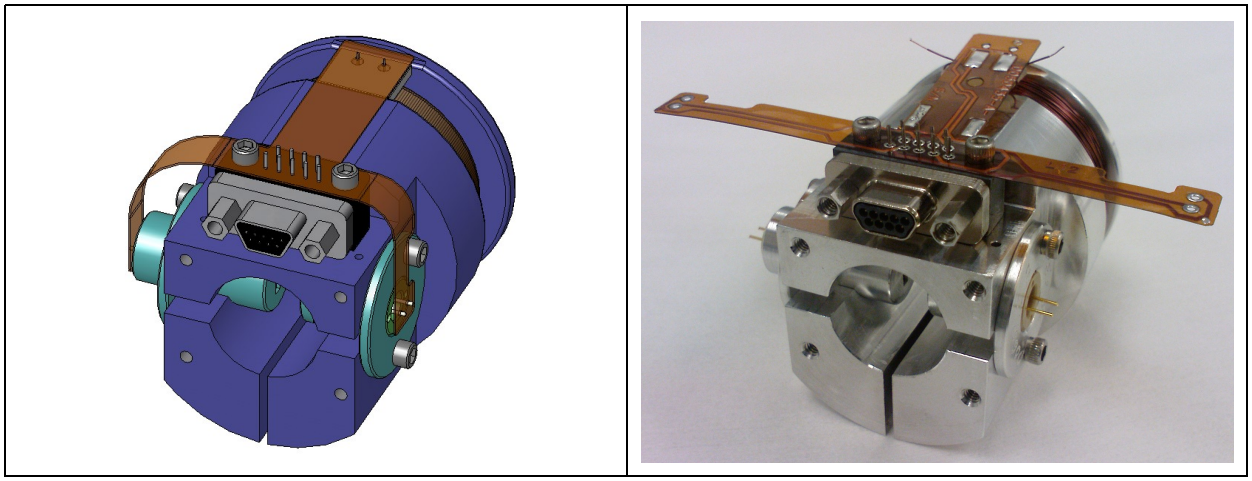

Figure 6. Coilformer and sensor assembly

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 Final 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 wind-off 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. 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 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).

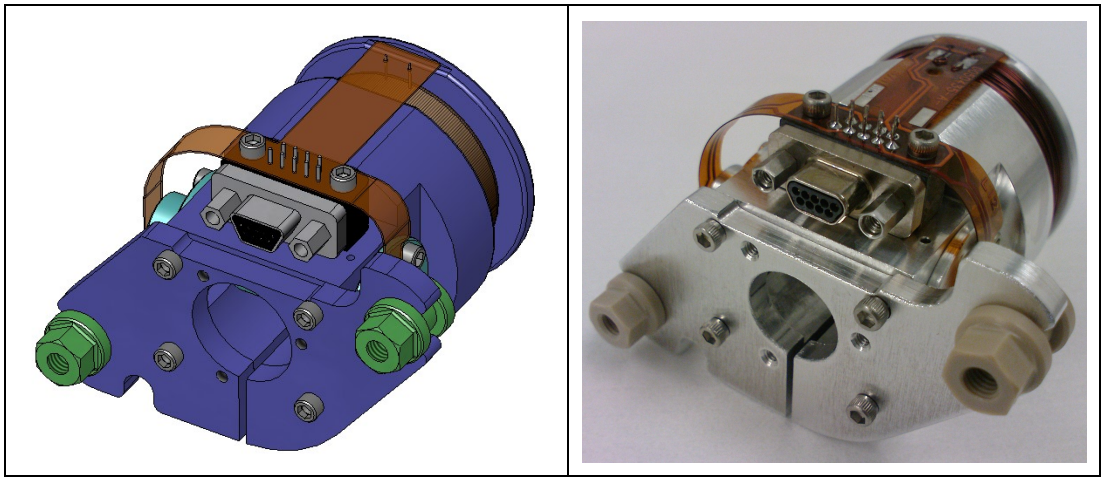

Figure 7a. Coilformer and backplate assembly

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.

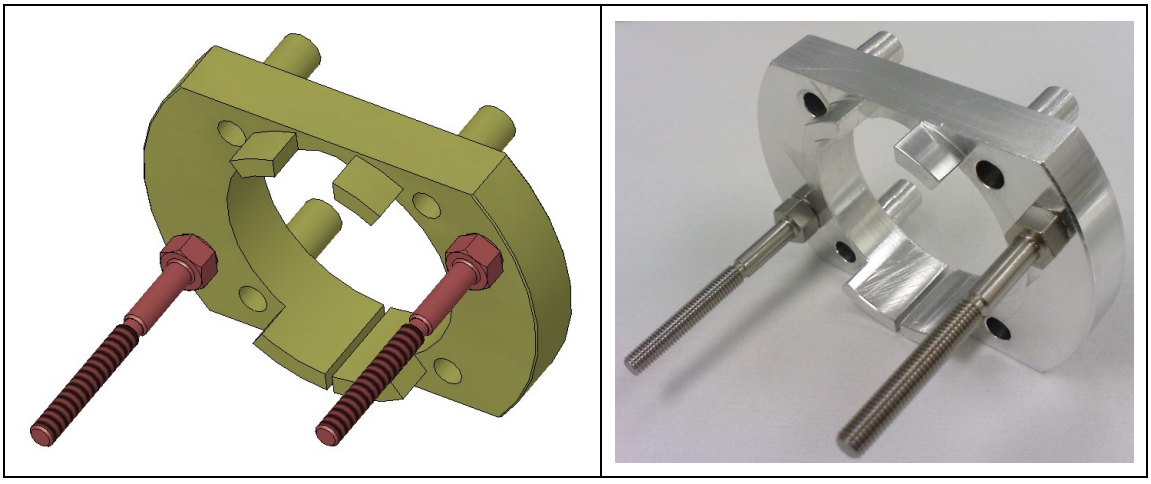

Figure 7b. Clamp assembly

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.

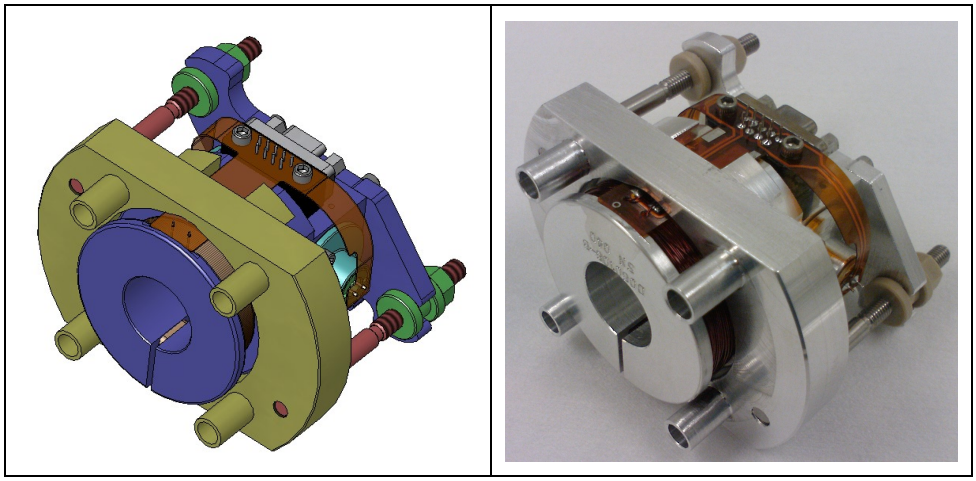

Figure 8. Completed BOSEM assembly

4.5 BOSEM Testing

The BOSEM will be tested and result data logged using the ATE as described in section 2.2 of reference [7].

20% of each shipped batch of completed BOSEMs are required to be characterized for noise (reference [9]) and sensor transfer function. Select the required number of devices at random from the batch (if batch contains BOSEMs with enhanced noise LEDs fitted, then the selection must contain a proportionate number of these devices), and perform characterization tests as detailed in reference [7].

All test results for each device will be logged, and the tests noted on the batch record sheet.

5 Final Clean and Bake

As described in reference [3], Soak in isopropyl alcohol for 10 minutes, agitating regularly. Finally, allow to dry in air for 24Hrs at 100^0C (to drive off alcohols before vacuum bake), then bake in-vacuum at 120^0C for 48 hours.

Remove from bake out chamber, record on batch record sheet, and wrap, bag and label per reference [3].

The record sheet, and all test results will be sent with the batch when shipped.