LIGO Laboratory / LIGO Scientific Collaboration

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The Design of the IGR MKII Strength Testing Machine (2008)

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Please note that this is in draft form.

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Revision History

Rev v1	*28th July 2010*	*First draft (R.JONES)*

Reference documents

Design documentation	
D1001879	IGR STRENGTH TESTING MACHINE (2002)
D080197	**IGR MKII STRENGTH TESTING MACHINE (2008) (TOP LEVEL)**
D080198	Drive Module
D080199	Load Cell Pull Assembly
D080200	Worm Wheel Drive Assembly
D080201	Pivot Test Assembly (not required for LIGO)
D080202	Adjustable Anchoring Assembly
D1001999	Central Pull Assembly
D1002003	Strength Tester Table
D1002009	Gearbox protector
D1002012	Worm Cap Assembly
D1002015	Strength Tester Phonebooth
D080686	Revised Disc Insert Assembly
D0900108	3x3mm bar holder,
D0900113	square ear holder
Reports and Presentations related to Strength Testing of aLIGO Monolithic Assembly Activity	
G0900108	Update on monolithic suspension work
G0900783	Update on monolithic suspension work Glasgow and MIT
T1000520	Summary of Welding and Tests (April 2009)
G1000436	Progress monolithic suspension work Glasgow and MIT since April 2009

1 Introduction

The purpose of this document is to describe the design and functionality of a multi-purpose strength testing machine (D080197, Figure 1 below) developed in Glasgow in 2008.

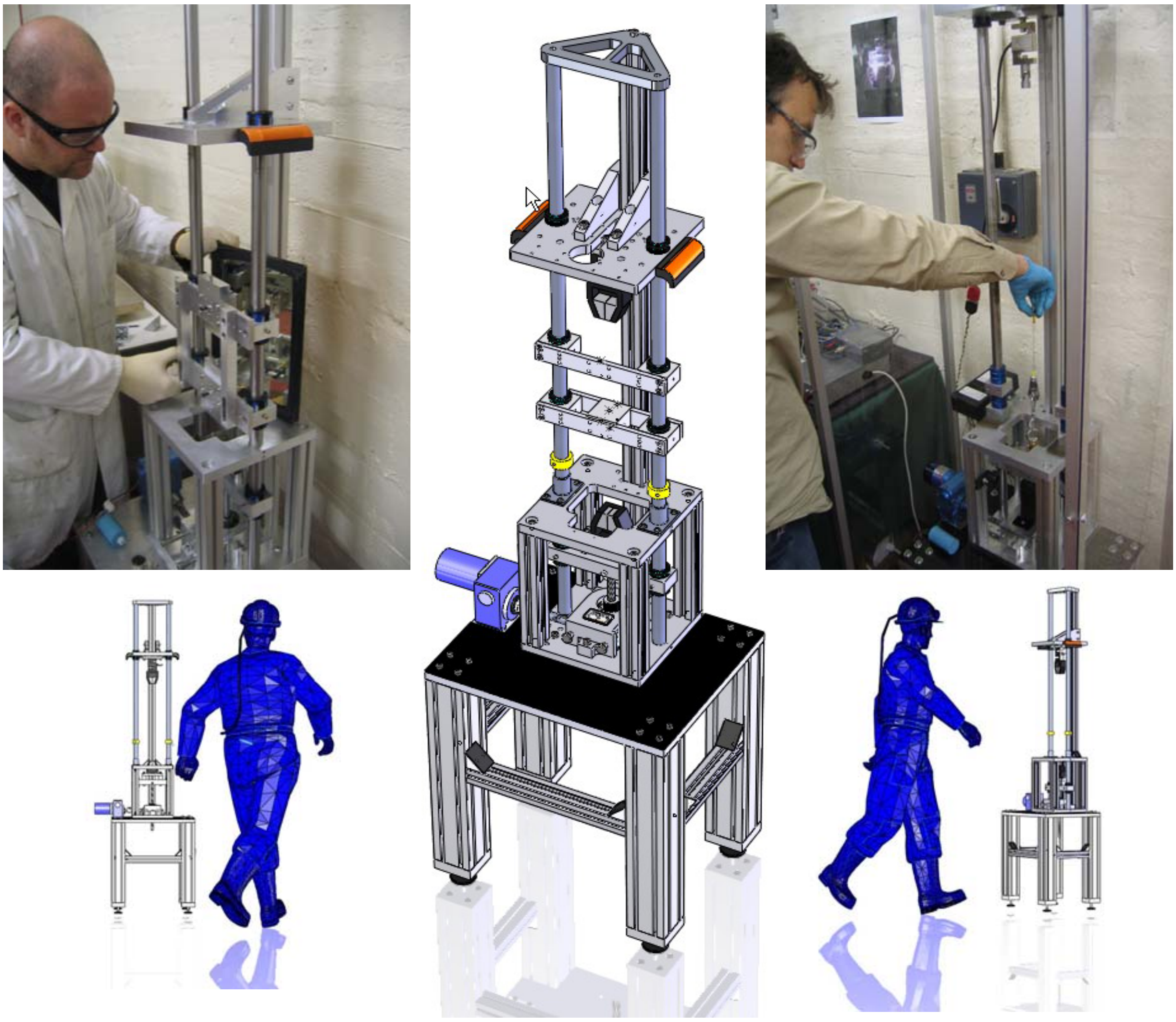


***Figure 1**: D080197 IGR MKII STRENGTH TESTING MACHINE*

It is a modular design, created in order to maximize the flexibility of the system for both current (aLIGO monolithic assembly) and future testing. Work on this new design was accelerated following the transfer of the first strength tester to LIGO mid 2008 (figure 2). As a starting point for this document, background on this alternative machine is provided (section 2), as it will be based at LHO now that the noise prototype is complete at LASTI. The new machine is described in section 3, and case studies for its use are attached in appendices of this document to illustrate the machine in use.

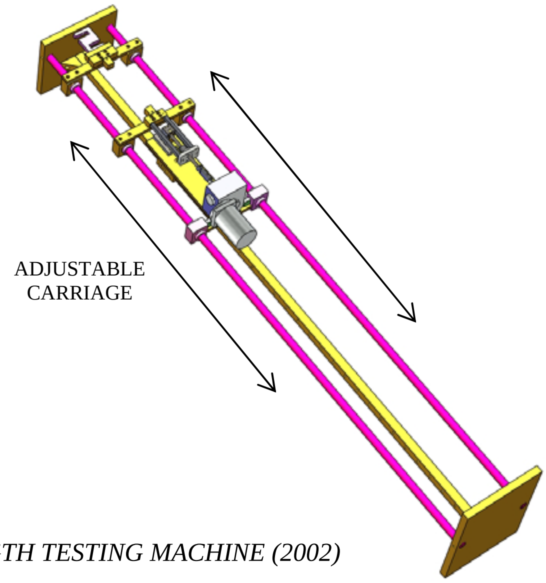


Figure 2: *D1001879 IGR STRENGTH TESTING MACHINE (2002)*

2 Background: Glasgow Strength Testing Machine (2002)

The first strength testing machine[1] developed in Glasgow, for destructive testing of ribbons and fibres, was designed by Alastair Heptonstall. This machine was transferred to LIGO (MIT) in 2008 when Alastair left Glasgow to work for LIGO.

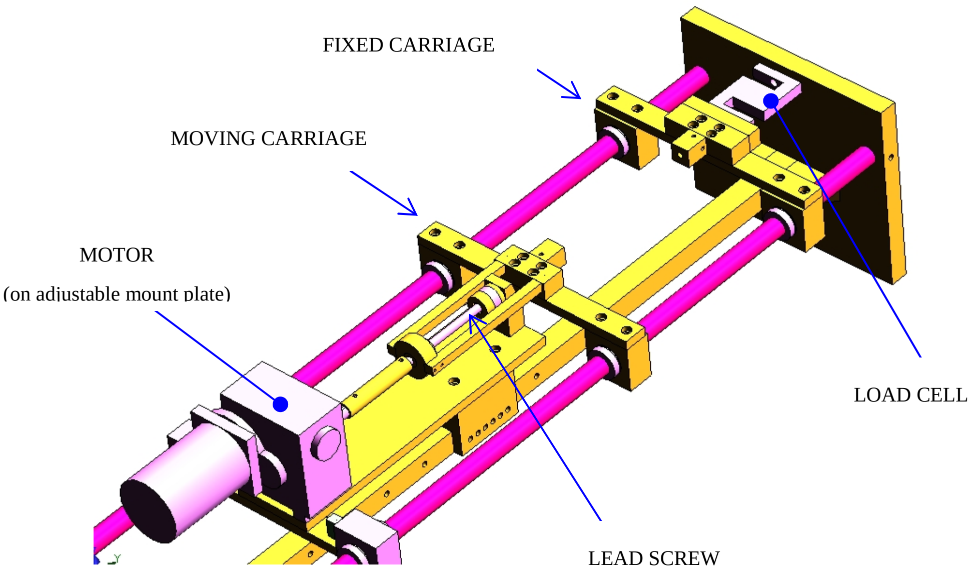


Figure 3: *D1001879, Mechanical close-up*

[1] D1001879-v1 IGR Strength Testing Machine Design (2002)

2.1 Machined parts

Should replacement mechanical parts be required for D1001879, the CAD files have been lodged on the PDM Works vault at the following location:

SUSPENSION>STRENGTH TESTING MACHINE>Strength Tester (2002)…D1001879

2.2 Motor

The motor used in D1001879 is the **Parvalux PM10C**.

Details: Permanent Magnet Motor / Double Worm Gear head [20rpm, 1050Ncm, 60W, 12Vdc]
Manufacturers Part Number: PM10C 12V + MIW GEARHEAD

2.3 Load cell

OMEGA S BEAM load cell LCM101 series. Capacity250kgF minimum suggested.

2.4 Precision rolled ball screw unit

The precision rolled ballscrew unit used in D1001879, is from "ABSSAC Ltd" should replacements be required. [Part number: MRB 0802]

A drawing showing the required sizes of this part is at:
https://dcc.ligo.org/DocDB/0013/D1001879/001/Strength%20Tester_ammendment_26thNov07_00.pdf

A replacement ballscrew has been required approximately twice in the past 8 years. This will of course vary depending on the frequency of use, and the extent of the loading, but the example provided corresponds to a period of consistent research usage for breaking fibres and ribbons. It is suggested that a spare be kept with the machine at all times if downtime (of up to a month for reorder/manufacture) is not acceptable.

[Though not currently a feature on the machine, note that a guard or cover over the critical areas may prolong the life of each unit, especially in keeping sharps away from the re-circulating ball bearings.]

3 The IGR MKII Strength Testing Machine

3.1 Design goals

The new machine was designed with a modular construction to maximize the flexibility, so not limit usage purely to the tensile testing of silica fibres. The design goals were:

- (Default configuration) vertical usage, but with option to adapt to horizontal usage
- Increased load capacity and robustness (compared with previous machine), such that bonds could also feasibly be tested in shear and tension.
- Maintain the adjustability of the previous machine for accommodating different sample lengths
- Fine control over speed of loading (again, to maintain option of bond testing in the future).
- To provide the facility to introduce rotation during loading (for drum ended wires)

(NOTE: Up until this time (July2010), only tensile tests of fibres, and also fibres welded to various silica substrates, including silicate bonded aLIGO production ears, have been carried out on the new machine. The pivot test assembly was meant for drum ended wire testing but never used. The assembly would require some additional design work in order for that to be implemented.)

3.2 Machine overview and key assemblies

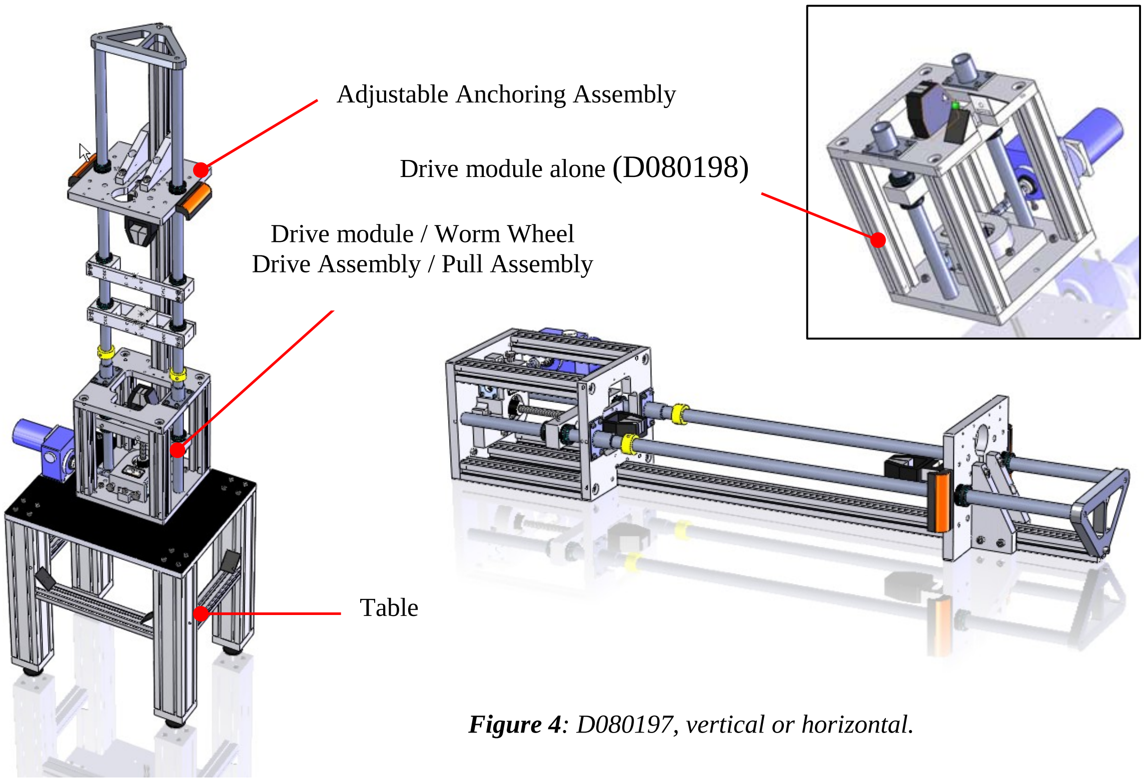


***Figure 4**: D080197, vertical or horizontal.*

Figure 4 shows the two possible configurations of the machine in use. The default is to use the machine vertically, mounted onto the table assembly (D1002003). The construction is such that if desirable, the drive module (including geared motor) could be disconnected and used independently if an application required it. The use of extrusion in the drive module means that it would be straightforward to fix to any given surface using angle brackets (e.g. "Set of angle brackets 8, 40x40mm, by ITEM, part number: 0.0.411.15")

3.2.1 Main mechanical assemblies

3.2.1.1 The worm wheel drive assembly (D080200) and drive module (D080198)

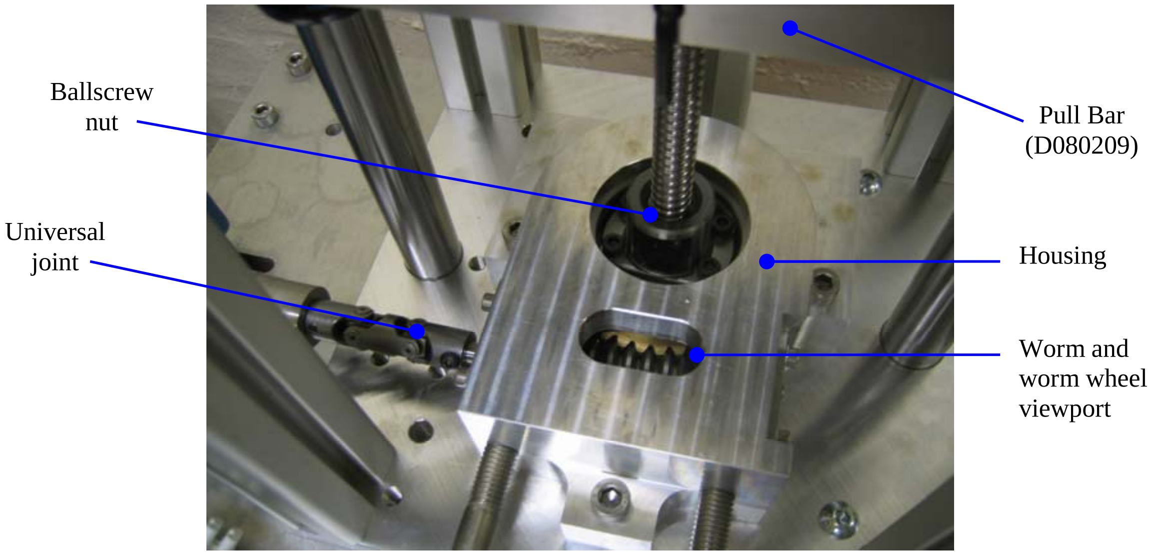


***Figure 5**: Worm wheel drive assembly (D080200) in situ*

The drive module (D080198) is home to the worm wheel drive assembly (D080200, figure 5), giving a 40:1 reduction to the motor speed, and associated increase in torque with the use of a phosphor bronze anti-backlash worm wheel, and a hardened steel worm. The anti-backlash wheel was selected in order to protect the motor from any recoil forces following destructive testing at high load. The worm wheel is sandwiched by two thrust bearings (one of which has an extra buffer from an o-ring, softening the contact with the base plate) in the housing (D080207).

The nut of the ball screw is rigidly fixed to the worm wheel, which ensures that the rotation of the wheel translates to a linear displacement of the ballscrew thread/shaft, which is pinned to the pull assembly (D080199) to prevent the thread rotating.

<u>*At full load</u>, if the system (electronics, geared motor and worm wheel drive assembly) was 100% efficient, with the maximum output speed of the motor gearbox (20rpm) achievable, after 2 minutes (40 revolutions of the geared motor) the worm wheel (and consequently the nut of the ballscrew) would have turned once, and displaced the pull bar (D080209) by 4mm (the specified pitch of the ball screw).

3.2.2 Load cell pull assembly (D080199)

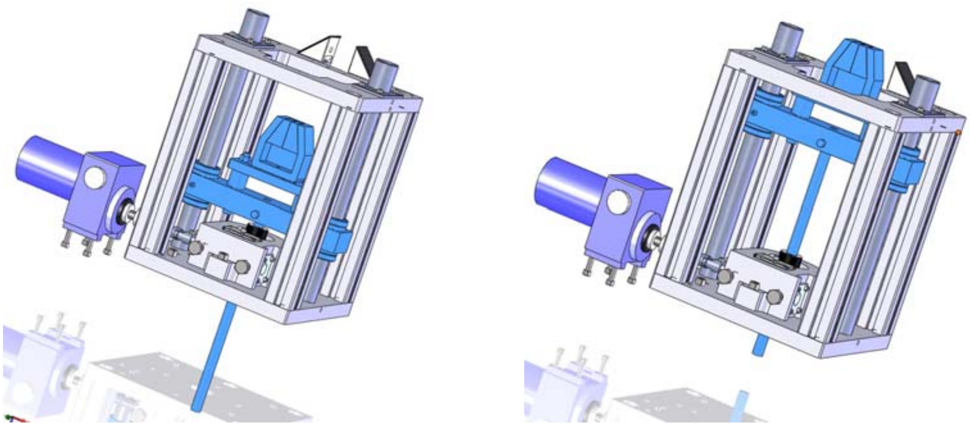


Figure 6*: Pull bar in lowest and highest position*

Under full load, the maximum pulling rate discussed in section 3.2.2 above, is ~2mm/minute. Motor speed should be set to a level that is sensible for the specific loading conditions of a given test (and predicted sample elongations).

The pull assembly (blue, in figure 6 above) has a maximum available range of around 120mm, depending on the choice of clamping interface. If the full range is being used, micro-switches to automatically cut off power to the motor, should be added at the top and bottom of the pulling range to avoid running the pull bar (D080209) into the gearbox housing (or top plate) and damaging the ball screw unit.

WARNING: THIS IS NOT CURRENTLY A FEATURE OF THE DESIGN SO CARE SHOULD BE TAKEN WHEN USING THE CONTROLS SUCH THAT THE RANGE OF THE PULL BAR IS ALWAYS CLOSELY MONITORED.

Note also, that the set-up time in terms of positioning the assembly to begin a new test (following a previous test) is limited by the maximum speed of the motor (i.e. 2mm/minute), using the motor specification from maximum loading condition. However, with no load, this may increase to ~5mm per minute, but this still suggests that setup could take more than 20 minutes if maximum pulling range is being used.

3.2.3 Adjustable anchoring assembly (D080202)

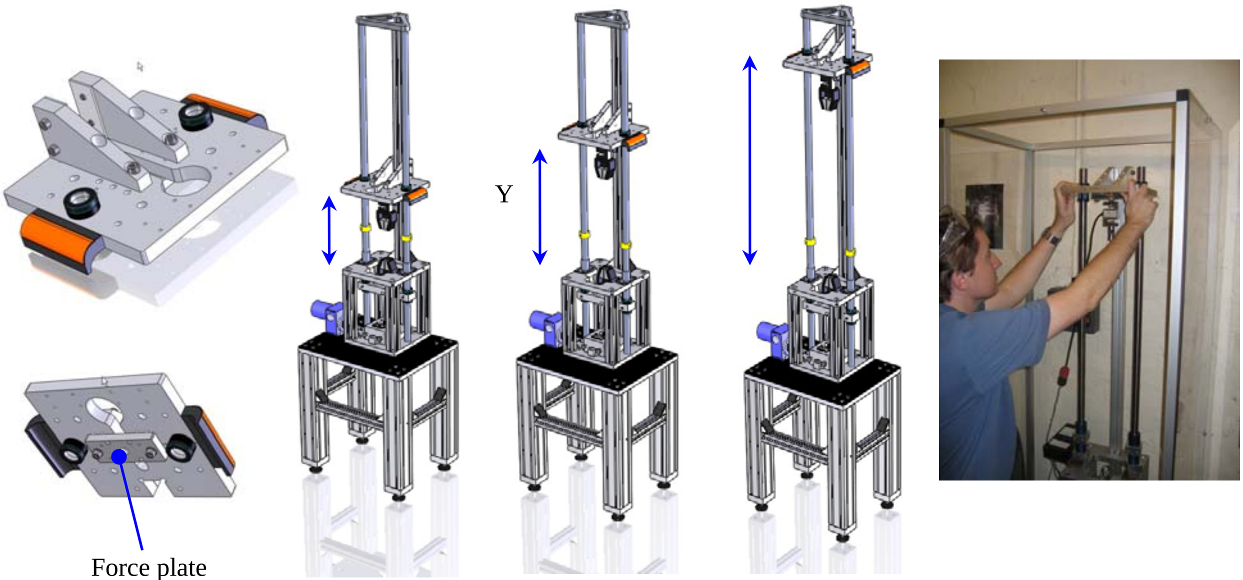


***Figure 7**: Adjustment of the anchoring assembly.*

Adjustment range, depending on the clamping or holding assemblies employed during a given test, should allow test lengths of 50<Y<800mm. Refer to drawing D080197.

This assembly includes multiple fixing locations for any number of possible tests. The force plate (D080210) is the same used in the pull assembly, so the load cell can be used in either the pull assembly (i.e. load cell moving, in connection with the pull bar), or in the anchoring assembly (i.e. load cell is static, as shown in figure 7 above).

3.3 Off the shelf components

3.3.1 Motor

As with D1001879, the same **Parvalux PM10C** is employed in the new machine design. The torque output is increased (and speed reduced) by a factor of 40 due to the added worm wheel gearbox

Details: Permanent Magnet Motor / Double Worm Gear head [20rpm, 10.5Nm, 60W, 12Vdc]
Manufacturers Part Number: PM10C 12V + MIW GEARHEAD

***Figure 8**: Motor connection and label.*

3.3.2 Load cell options

There are two load cells that are suggested for this machine.

For higher load tests (>100kg) use: LCM101-1k by OMEGA. A meter is required with this (DP25B-S Meter) and useful extras include a rod end (MREC-M12M) and load button (MLBC-M12M)

In recent cartridge tests of aLIGO monolithic assembly activity, the following load cell (figure 9) was used: XLS2-250 by Load Cell Central.

Figure 9*: Load cell detail,* XLS2-250 with meter

3.3.3 Precision rolled ballscrew unit

The precision rolled ballscrew unit used in D080197, again from "ABSSAC Ltd", is the MRB1404B 280R300 C10-50

(Machined to spec as per R.JONES email to Phil Jones, 17/08/06: 280mm thread, 300mm overall length, 1 off journal 20mm long, 11mm diameter, with 6mm pin hole 10mm from the end, MRB1404B NUT, see figure 10).

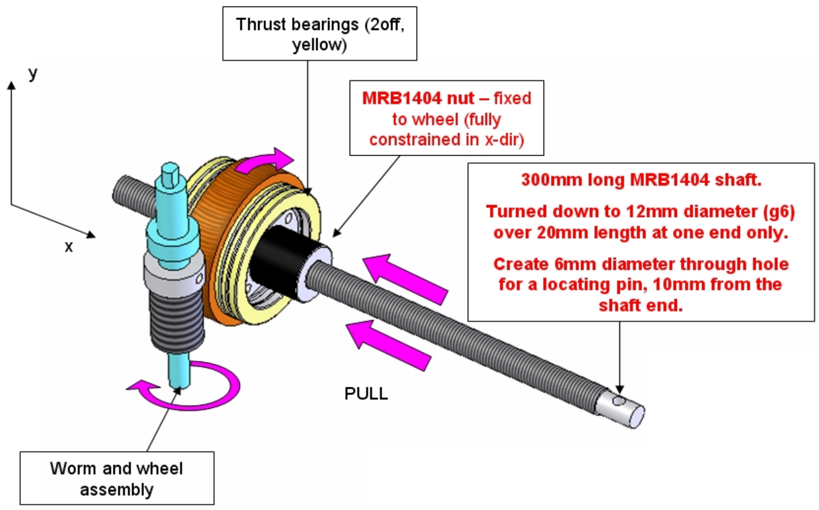


***Figure 10**: Sketch from email to Phil Jones of ABSSAC Ltd*

3.3.4 Bearings and bearing poles

The bearing poles employed are manufactured by SKF, purchased in the UK from RS Components: 25mm diameter (SKF) LJM bearing shaft (LJM25 x 1000). (RS number: 285-0403). This material is also cut to size in D080206.

The linear bearings that go with the poles are also manufactured by SKF: Linear Bearing (SKF) LBCR 25 (RS number: 284-9784). These bearings are used in the adjustable anchoring assembly (D080202) and the load cell pull assembly (D080199) only. They had also been employed in the central pulling assemblies (D1001999), but the unsuccessful first cartridge test of the obsolete aLIGO ribbon ears with welded fibres (October 2008), highlighted the possibility that chatter/vibration in the bearings might be an undesirable side affect if using the re-circulating linear bearings.

As a result, all four bearings used in the central pulling assemblies (that provide stability to samples during a strength test) were replaced with plain bearings. The plain bearings now used are:

Frelon liner closed bushing, 25mm ID. (RS Number: 217-9726. Manufacturer: Pacific, part number: FMC25)

3.3.5 Off the shelf clamps, and custom clamping assemblies

***Figure 11**: Wedge action grips, GF-11 by Lloyd Instruments*

Traditionally used for breaking ribbons on the first strength tester (where the glass was sandwiched by a few layers of cardboard as shown in the far right image in figure 11 above), these clamps, with self-tightening wedge grips, are very useful to have available for general strength testing requirements. (GF-11 Capacity: 2.5 kN, 562lbf)

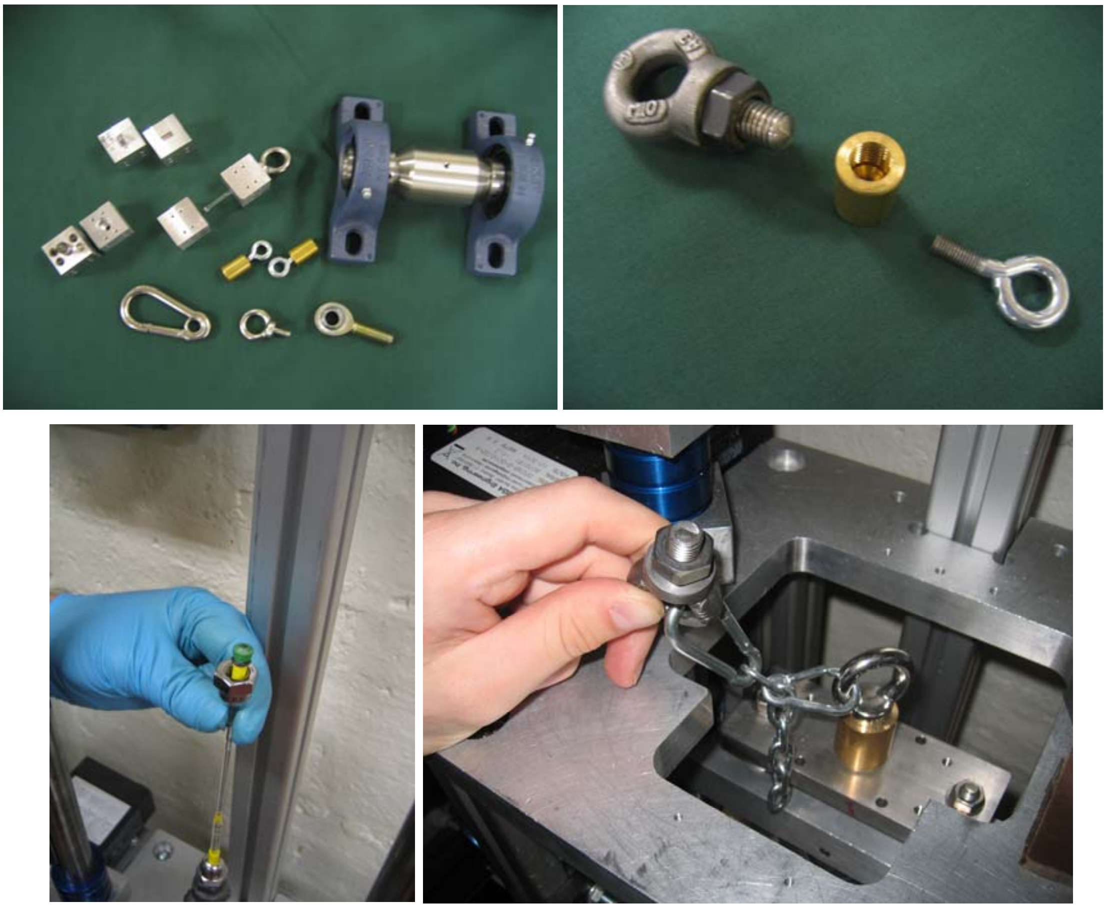


***Figure 12**: Customized clamping assemblies*

Figure 12 shows various clamping assemblies developed for testing of silica fibres and welds. Eye bolts (M4/M6/M8/M10) and carbine hooks are needed in most strength tests. Chain and universal joints are also frequently used. Dome nuts are re-machined to create a clearance hole for silica stock in specialised fibre break tests (by K. Tokmakov).

Refer to appendix 1.

3.4 Motor Controller Electronics

The circuit (figure 13) uses pulse-width modulation to vary the motor speed.

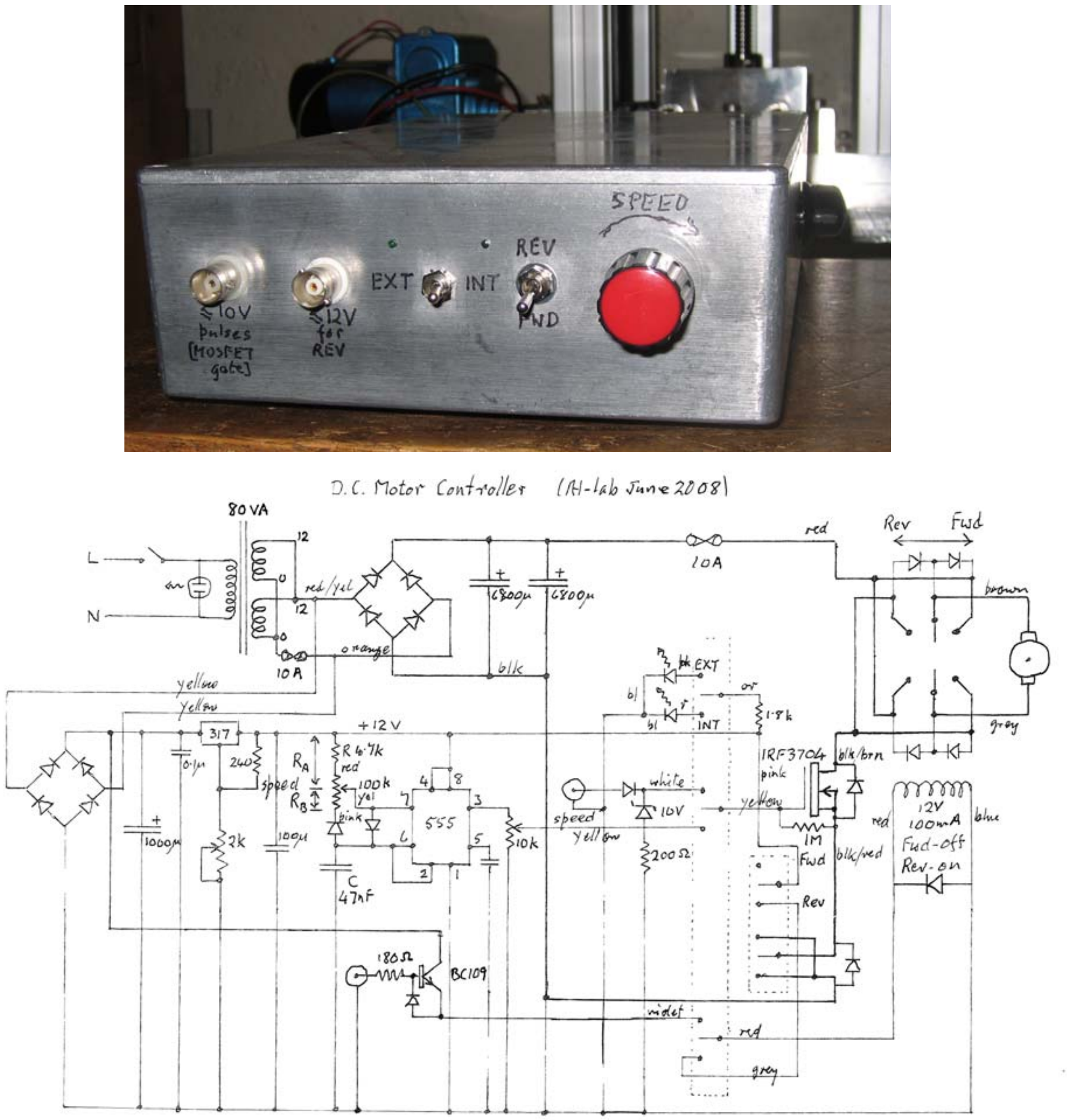


***Figure 13**: Motor control box and circuit diagram by Alastair Grant*

3.4.1 Speed control

The low power supply is regulated to 12 volt by the LM317 for the 555 timer. The timer outputs a square wave of amplitude 12 V at pin 3 and a suitable fraction of this is supplied to the gate of the MOSFET by the pre-set 10 k. The frequency is fixed at approximately 300 Hz by the values of R_A, B_B, and C. The 100 k potentiometer varies the mark/space ratio from 100% mark to a small value of mark set by the 4.7 k resistor. This resistor prevents excessive current drain by the 555 which occurs at very low values of mark/space ratio. The MOSFET is in the return path of the high power motor supply. When the mark/space ratio is small the MOSFET is on for only a small part of the cycle period and the power supplied is small resulting in low motor speed. At 100% mark the MOSFET is on all the time giving maximum speed.

By setting the four pole function switch at “Ext”, pulses from a computer may be applied to the gate to control the speed instead of using the internal oscillator.

3.4.2 Forward / Reverse

The relay operated double pole – double throw switch provides “Forward” and “Reverse”. Diodes are wired at the contacts, between the drain and source of the MOSFET, and at the switch to deal with the voltage pulses produced by switching off current in the inductance of the motor. The Forward/Reverse switch has a centre “off” position and the wiring of the other half of this switch ensures that the power is off when, after a short delay, the relay contacts open.

Again the “Ext” setting allows the Forward/Reverse to be controlled by a computer signal on the base of the BC109 transistor. However, the power is not automatically switched “off” when this function is operated, and **it is the responsibility of the user to see that there is zero voltage on the MOSFET gate during the time that relay contacts are opening when the direction of rotation is changed by this means.**

3.5 Load limits for the machine

<u>WARNING:</u> It is recommended that the machine should not be used to break samples at loads above 100kg.

The main parts and assemblies are chosen for high strength and high factors of safety to prolong the life of the machine. The following table details the critical information and maximum load limits of each the main design features.

Assembly/Product	**Limits**	**Comments**
Parvalux PM10C Geared Motor	10.5Nm/20rpm/12Vdc	Numbers relate to maximum loading condition from the basic motor specification
MRB1404B Ball screw unit	Axial load, F = 4.56kN	Manufacturer's guide, 80% basic rated dynamic load of 5.7kN (governed by the stiffness of the nut mounting and related parts)
Worm wheel drive assembly (D080200	3299 kg	See appendix 1 for calculations
Electronics	10A	Fuse rating to prevent overload or work above a certain limit

Strength of frequently used sub-components within the machine, such as the clips (above) which deformed at 93kg, further justify restricting the maximum load to 100kg.

3.6 Safety

3.6.1 Optimised machine stiffness

The weakest points of the system are in the adjustable anchoring assembly. Deflection of the adjustable top plate at high load can occur due to slack in the fit of the linear bearings (D080216), and rotation in the connection between the spine (D080214) and the gusset plates (D080218). In figure 14, the triangular end cap (i) is a feature that has been added to act as a tie between the bearing poles and the spine (iii). This is an essential feature if the machine was to be used horizontally, but is not a necessity when in the default vertical configuration where gravity prevents any dislocation.

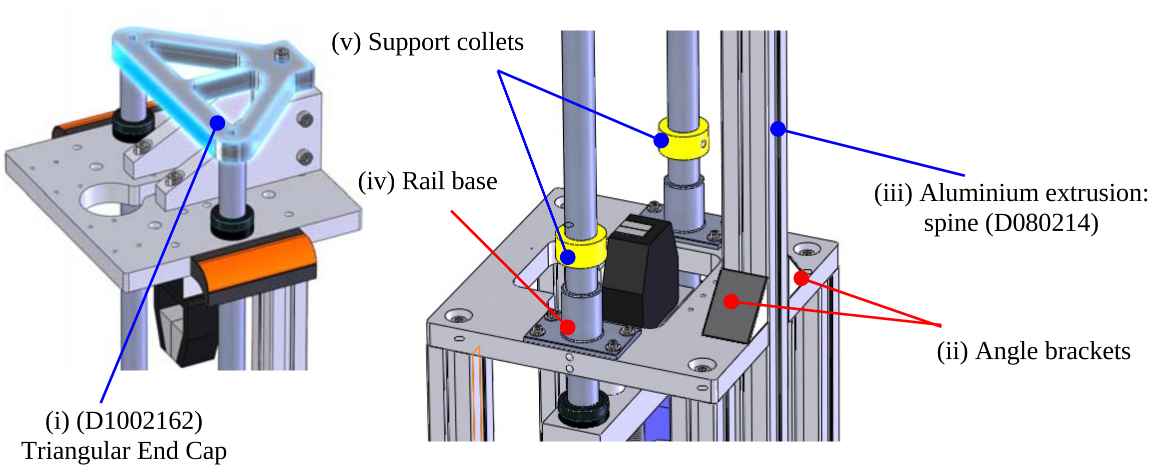


Figure 14*: Necessary elements for optimised machine rigidity*

It should be noted that the use of angle brackets at location (ii) in figure 14, though not essential, will optimise the overall rigidity of the system. Similarly, rail bases (iv) for the bearing poles are a useful feature, especially for vertical use in the absence of the end cap.

The support collets (v) are lockable buffers/stoppers that can be positioned to catch the central pulling assembly when a sample breaks.

3.6.2 Protection around the drive unit

Bellows protect the ballscrew assembly from sharps and debris, and a plastic cap protects the inner workings of the drive assembly (figure 15). The use of a (wipe-able) shiny black plastic tablecloth (D1002008) makes any dust or sharps far more visible for users during cleaning of the machine.

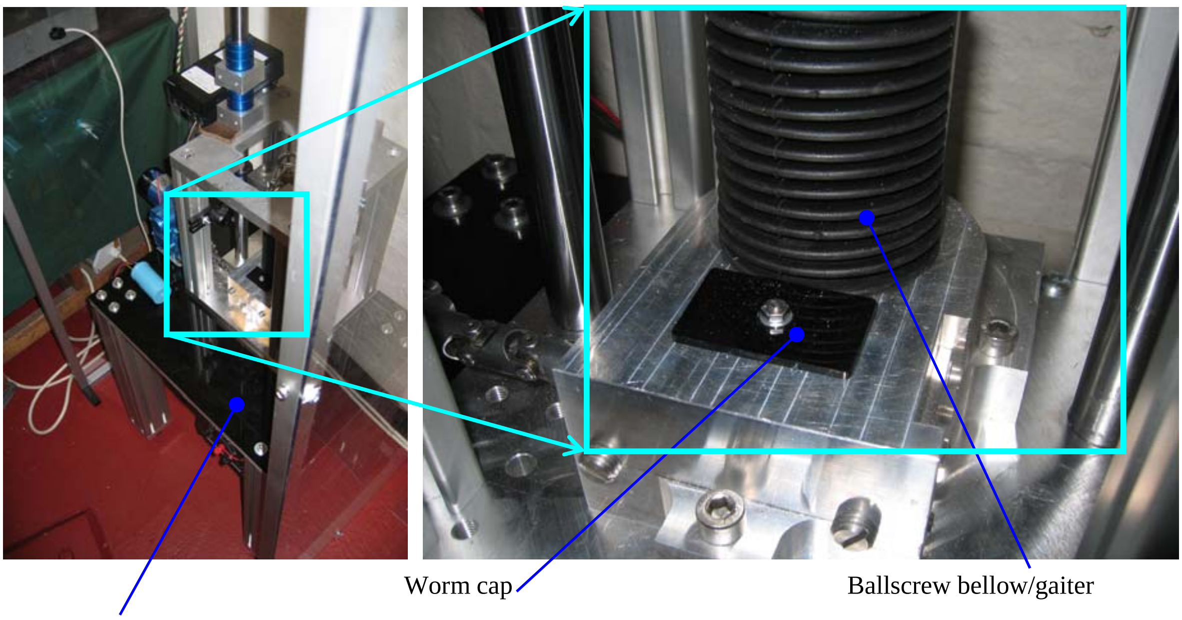


***Figure 15**: Basic protection of the ballscrew and gearbox workings*

3.6.3 User protection: the phone booth assembly

***Figure 16**: Screening of strength test: the phone booth*

When breaking samples, users of the machine should be screened appropriately at all times, using the basic enclosure (D10020015 Phone booth assembly). Debris/sharps/silica dust resulting from a destructive test of a silica fibre at high load can be seen in figure 17.

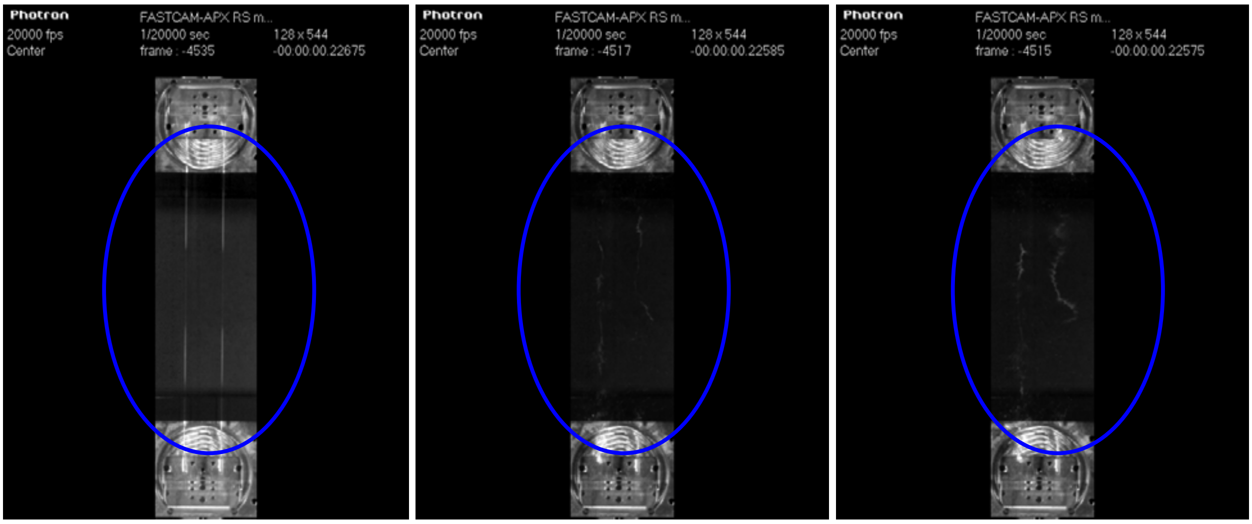


Figure 17: Cartridge test of fibres welded to aLIGO production ears – fibre fracture stills

3.6.4 General maintenance

- Ensure all bolts are properly tightened before beginning a test.
- The worm wheel drive assembly should not be run dry – ensure that components are greased prior to the first run.
- Regular vacuum cleaning should be performed after every test, to minimise risk of harm to both the user and to the machine's critical components.
- Load cell calibration should be carried out in accordance with the manufacturer's guidelines.

4 Conclusion

The new strength testing machine is an able replacement, and has more versatility than its predecessor.

- The drive components are capable of sustaining load levels that are at least four times above the suggested limit of 100kg. The limit is set to prolong the life of the key design components, most notably the ballscrew unit.
- The machine can operate in either the default vertical or horizontal configuration.
- A pulling rate of ~ 2mm/minute is achievable at full load
- The range of the pull assembly (in the drive unit) is ~120mm, and is not currently limited by micro-switches, so due care and attention should be taken with the position of the pull bar during a given test.
- Sample lengths of 10mm<y<800mm should be applicable for testing in the available pulling volume, though limits within that range (at the high end) depend ion the clamps and the specific fixtures used in the test
- The machine should be frequently cleaned (vacuum cleaned and wiped) to minimize risk of damage to the critical components, and also to optimise user safety during use.
- The machine should always be screened during a test
- For maximum flexibility, extra tooling holes exist in the anchoring assembly (and central pulling assembly) to ensure that future samples and designs can be retrofitted into the test volume.

Note to LIGO staff: Please feedback any design issues, additions/alterations or suggestions to staff in Glasgow.

<u>Disclaimer</u>: The inclusion of a particular manufacturer/supplier does not mean that we endorse the use of their product over that of another manufacturer/supplier.

5 Case studies: Machine operation

5.1 Fibre strength tests

Strength tests of fibres can be performed in two ways.

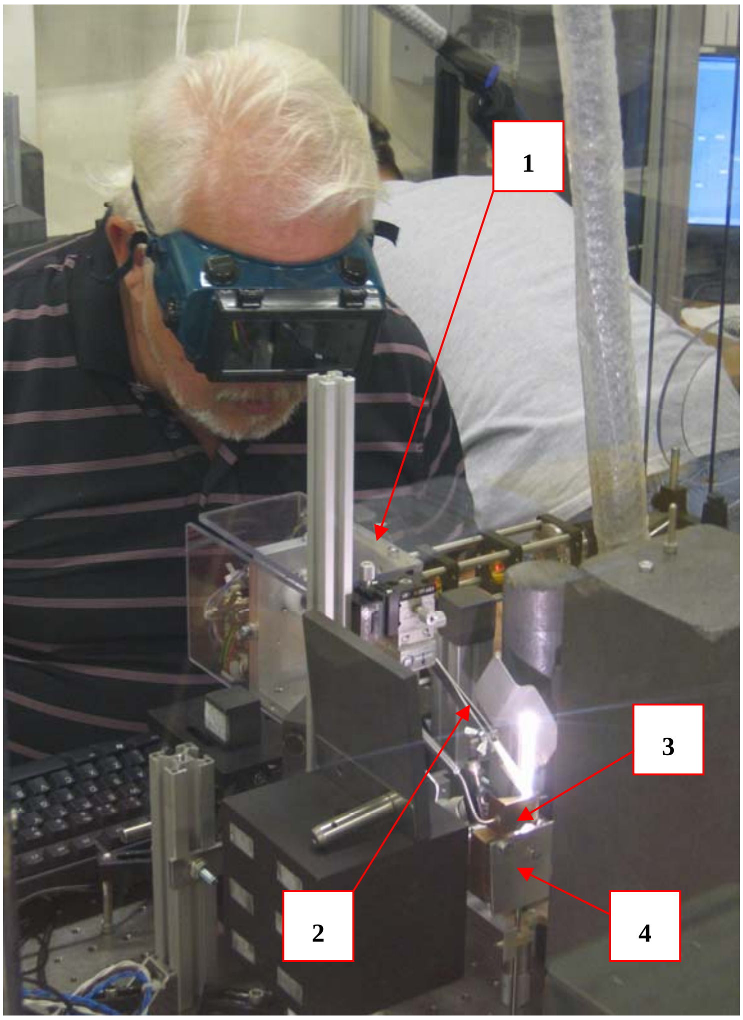
Firstly, using the more traditional clamps shown in figure 11 of section 3.3.4, or using the components developed by Kirill, as shown in the bottom left image of figure 12. It is not worthwhile testing an aLIGO fibre in its fuse ends (D080017), as the adhesive bond between the stock and the fuse is not strong enough to test a fibre to destruction.

Kirill uses a set-up where dome nuts are re-machined to create a clearance hole for silica stock. Larger diameter silica rods with ball ends (a customised creation by Kirill), to which the chosen fibres can then be welded. The silica is protected by shrink wrap around the ball end and around the thick stock near that location. An o-ring is used directly below the base of the ball joint to distribute the forces during a tensile test. An indium gasket on top of the ball joint protects the stock when the dome nut connects to an adjacent assembly (i.e. eye bolt).

These parts are versatile, and can be used either as a pair as shown above, or in isolation with another flavour of clamp.

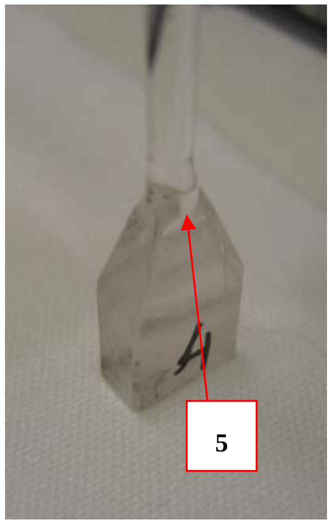
5.2 Basic weld testing: 3mm silica stock to GEO style ear

Background: As training for the aLIGO monolithic assembly process, welding of Stock to GEO style ears in a significant step prior to attempting welds to the final ear design due to the cost and importance of each production ear.



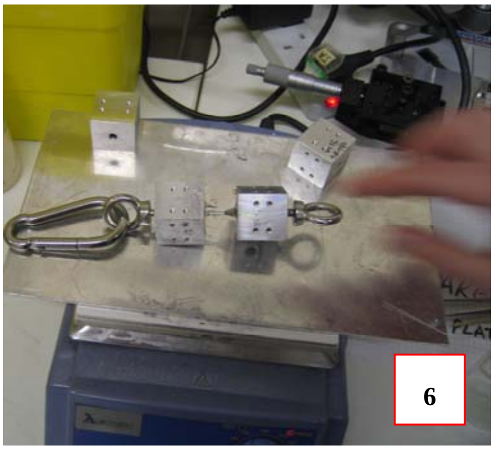
KEY:

1. Birdcage
2. tweezers on translation stage
3. mirror
4. weld hub
5. Test specimen: resulting weld of 3mm stock to GEO style ear

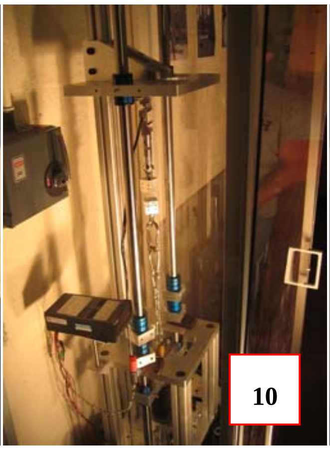


Set-up: Bench top welding using a derivative of the same welding equipment (hubs, mirrors, tweezers and the birdcage) that is required for the final aLIGO monolithic build.

Tweezers holding the stock during welding (simulating the fibre bow) mounted to translation stages, fixed to optical bench. Array of graphite blocks positioned to isolate space around the weld test and catch stray reflections.

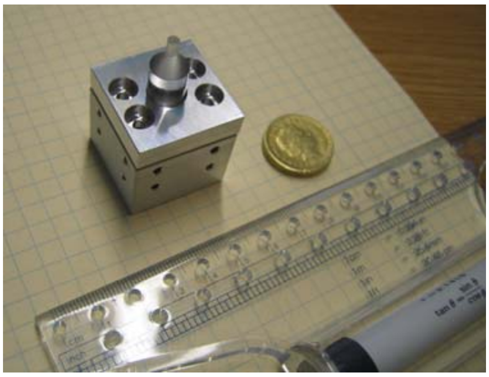


Test specimen waxed into two clamps (“D0900108_3x3mm bar holder”, for the stock. “D0900113_square ear holder”, for the GEO style ear). To do this, the clamps are placed on a hot plate (~170 degrees C), as in image 6 above, and the wax is introduced before adding the specimen. The resulting assembly, once cooled for the wax to set, is installed into the strength tester as shown in 7 and 8.



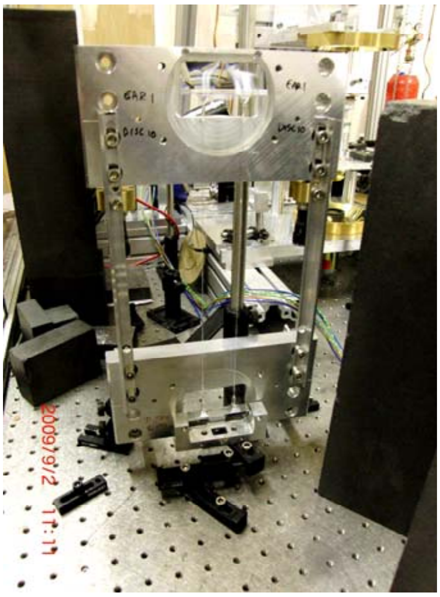
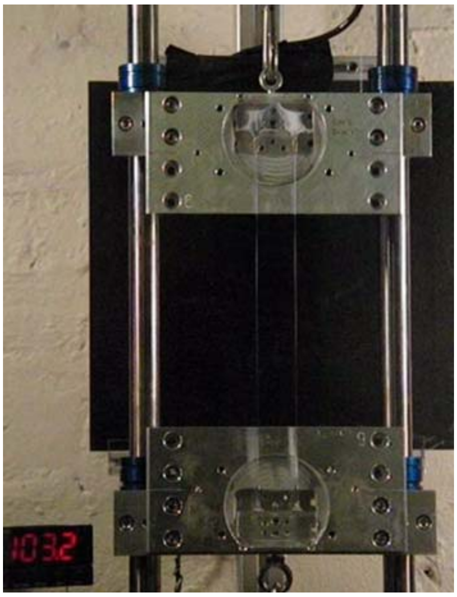
An example of the expected strength of the assembly, in two tests performed in the weld training in Glasgow (August 2010), the welds in this set-up, were tested to a destructive load of 42.8kg and over 80kg. Breakage occurred in the stock in both cases, not the weld.

Similar tests can be performed with round ears, as shown below.


5.3 Breaking aLIGO composite bonded/welded assemblies

To be added.

Appendix 1: Worm wheel drive assembly calculations

The motor/gearbox unit has a maximum torque of T = 10.5 (N m) at 20 rpm.

One turn therefore takes 3 seconds, and the work done per turn is- pi x T (J).

The power is- pi x T/3 = 11 W. Neglecting losses, this corresponds to a current of 0.916 A at 12 V, well within the capability of the power supply.

One turn of the lead-screw moves the load, F (N), by a distance of 4 mm, so the work done is-0.004 x F (J). The worm and gear have a velocity ratio of 40:1, so this requires 40 turns of the motor/gearbox which at maximum torque amounts to work done of- 40 x pi x T (J). Again neglecting losses, equating these gives-

0.004 x F = 40 x pi x T.

Thus the maximum load, F, is- 40 x pi x T/0.004 = 10000 x pi x T = 32986 (N).

This is equivalent to the weight of a mass of 3299 kg or 3.299 metric tonnes.