LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO- T1000239-v1 *ADVANCED LIGO* 10 May 2010

CO_2 laser pulling machine for fabrication of fused silica suspension fibres

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1 Introduction

1.1 Purpose and scope

The CO_2 laser machine set up is used for the fabrication of silica fibres and was designed and prototyped within the IGR, University of Glasgow. This manual provides an overview of the design and description of the set up and its operation. A description of the alignment procedure of the system, software involved for machine control/signal processing and fibre pulling technique has also been discussed. The previous versions of this manual can be found at LIGO DCC- T060242-D

2 Equipment and Materials

CO_2 laser machine

Sets of gold plated mirrors

Beam splitter

Graphite enclosers

Power meter (for measuring laser power)

Silica (Hereaus p/n 09685082) stock material

Diamond tip cutters

Pointer beam (usually attached to the laser machine)

A P4 or higher spec computer for Labview operation

Alpha 10 wipes – VWR Cat. No. TWTX1010 – (case)

Gloves - VWR Certi-Clean Class 100 Latex Gloves or Accu Tech Ultra Clean 91300 Gloves.

Methanol - Reagent grade

Acetone – Reagent grade

Suction pump (exhaust HEPA filtered vaccum cleaner for extracting silica vapors)

Chiller for continuous cold water supply

Pulling machine (comprises of motors and other parts listed in DCC no D070560-v1)

3 References

D070560-v1	ALIGO SUS CO2 Laser Machine_Overall Assembly_[CO2_GLA_ASM_OVERALL]
D060150	aLIGO_SUS_CO2 Laser Machine_Conical Mirror FEED Assembly_[CO2_GLA_ASM_05]
D080404-v1	aLIGO CO2 Laser Pulling Machine_Monolithic Assembly Tooling_Fuse Assembly
D070551-v2	aLIGO SUS ETM/ITM Monolithic Assembly_ Fuse Jig
D060149	aLIGO_SUS_CO2 Laser Machine_Spinning Mirror Assembly_[CO2_GLA_ASM_04]
D060146-v1	ALIGO_SUS_CO2 Laser Machine_Twin Ballscrew and Support Frame_[CO2_GLA_ASM_01]
P0900095-v3	Investigation of mechanical dissipation in CO_2 laser drawn fused silica fibre welds
T060242-00-D	Characterization and intensity stabilization of a high power CO_2 laser for fibre pulling
T1000367	Codes for polishing and pulling silica fibres
P1000080-v1	CO_2 laser production of fused silica fibres for use in interferometric gravitational wave detector mirror suspensions/

4 Machine overview

The major components of the set up for fabricating silica fibres are a 100 W laser and a pulling machine (mainly a configuration of twin motors, arms and conical mirror set up). The laser used here is a Synrad Firestar f100 series 100 W continuous wave laser (10.6 µm). The laser set up requires a continuous supply of water to act as a coolant. Adequate training and safety measures should be adopted before operating this laser (refer to the safety section of this manual). The pulling machine is specifically designed for the fabrication of fibres of few hundred microns in thickness from silica stock material. It consists of twin motors and two arms. The motors drive their respective arms in either up or down directions. The lower arms have conical mirror and rotating mirror arrangements to provide symmetric heating of the stock material. A full description of this machine is discussed in section 5. The SOLIDWORKS design of parts and various components of the pulling machine can be found at LIGO document – D070560.

Once a fibre is polished and pulled it then undergoes various levels of quality testing and characterisation, described as a block diagram in figure 1.

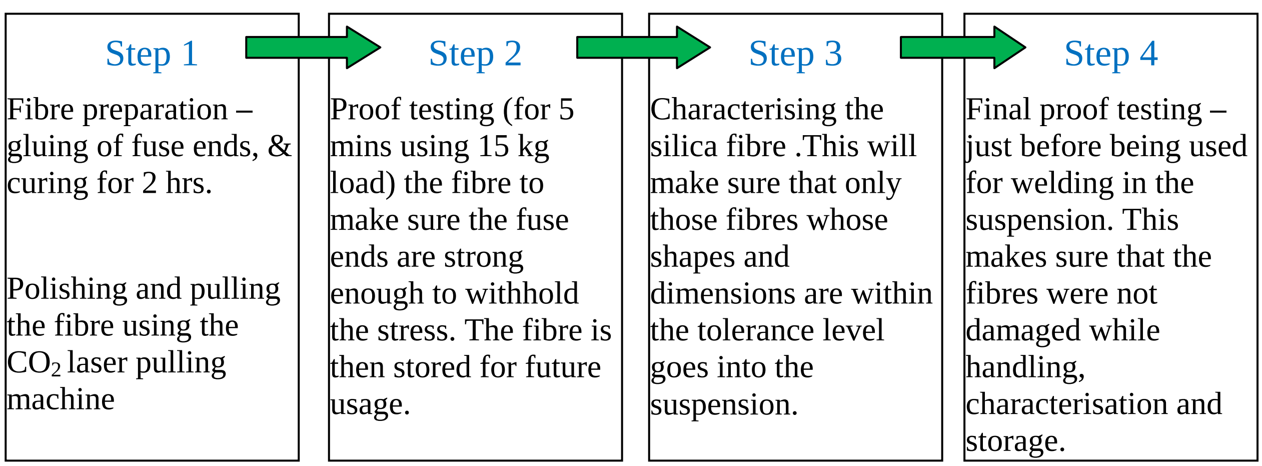


Figure 1: Block diagram showing the fibre pulling and various characterisation processes before being welded into a suspension.

5 Design and description of the fibre Pulling machine

The CO_2 laser pulling machine works on the concept of feed and pull. A continuous supply of silica material (silica rod) is fed to the laser beam to be melted and to stock the reservoir of molten silica from which the fibre is slowly pulled. The ratio of the feed and pull speeds can be carefully adjusted to control the diameter ratio between the drawn silica fibre and the silica stock material. The fibre radius is given by $(v_1/v_2) = (r_1/r_2)^2$ with v_1 is the feed speed, v_2 is the pull speed, r_1 is the fibre radius and r_2 is the stock rod radius. Using this technique and by accurately varying the feed-pull ratio, precisely controlled fibre shapes can be produced.

Figure 2 illustrates the conceptual design of the machine based on this ‘feed and pull’ technique. Fibre stock material (silica rod of diameter r2) is held rigidly between the base clamp and upper clamp in the machine. The 10.6 μm laser beam has a red laser diode beam (tracker beam) superimposed for visualization and beam alignment purposes. The combined beam enters the machine horizontally and is reflected vertically downwards from a fixed 45 degree gold coated mirror. It is then reflected off a second 45 degree gold coated mirror which is motorized and spins around its vertical axis (8.6 voltage supply). The resulting beam rotates in a horizontal plane and is reflected off the lower fixed conical gold coated mirror and reflected vertically upwards towards the upper conical gold coated mirror which travels slowly downwards on a moving carriage (at speed v1). In this way, the laser beam which rotates in a ring providing uniform heating around 360 degrees is slowly fed into the silica stock (rod) adding material to the molten reservoir. Simultaneously, as the laser beam is slowly fed into the stock material (at speed v1) the upper clamp on the stock material moves vertically upwards (at speed v2 > v1) drawing the fibre from the molten silica reservoir.

Both the feed (upper conical mirror) and pull (upper clamp on stock material) components are mounted on slow mechanically actuated carriages on precision ball-screw units. The high performance motors with reduction gearboxes minimize backlash effects in the drive system. These are used to drive the carriages which are precisely computer controlled using a specially written Labview control program for the pulling process. Good position control is achieved using high precision linear encoders sensors (including magnetic tape and readout heads).

The upper and lower stages of the machine are shown in figure 4a. The lower conical mirror along with rotating mirror can be seen in figure 4b. The top mirror shown in figure 4b is fixed and is the point of entry of the laser beam into the pulling machine. Figure 5 shows a piece of silica stock being heated by the laser beam and the top clamp slowly moving upwards to pull a fibre. The lower mirror is slowly moving downwards to feed in more molten silica. Also seen is the Firestar f100 laser machine in figure 5.

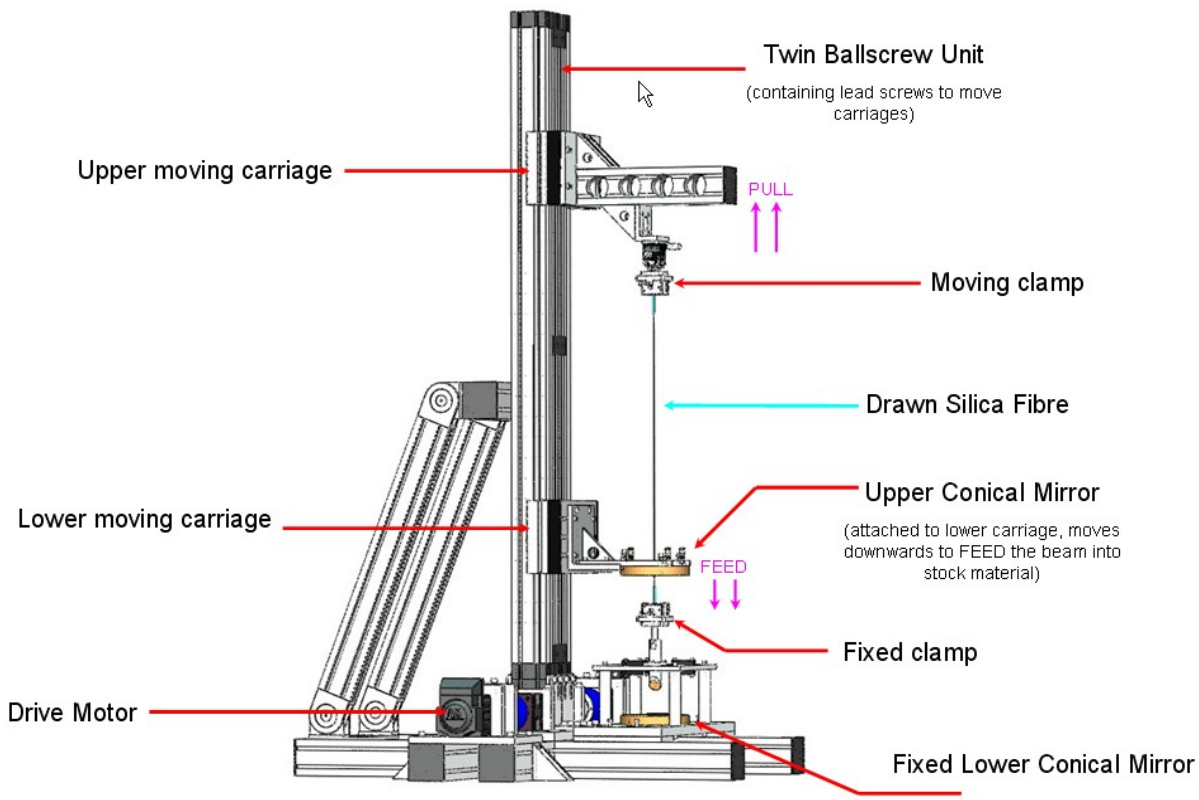


Figure 2: Fibre stock (silica rod) is held between the base clamp (fixed) and the upper clamp (moving). The 45 degree conical mirror arrangements are designed so that the path of the laser beam is a rotating ring thus melting the stock material evenly around 360 degrees. The upper conical mirror moves slowly downwards (slowly feeding new stock material to the molten reservoir) whilst the upper machine clamp draws the fibre. The system is computer controlled using Labview.

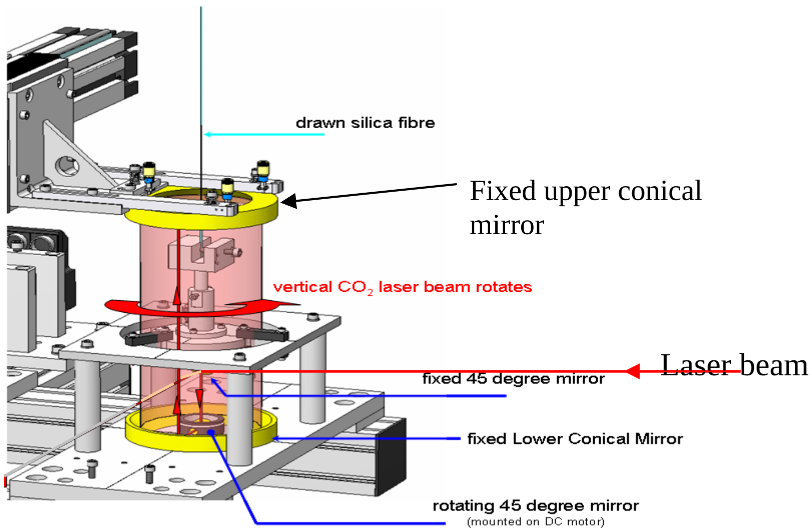
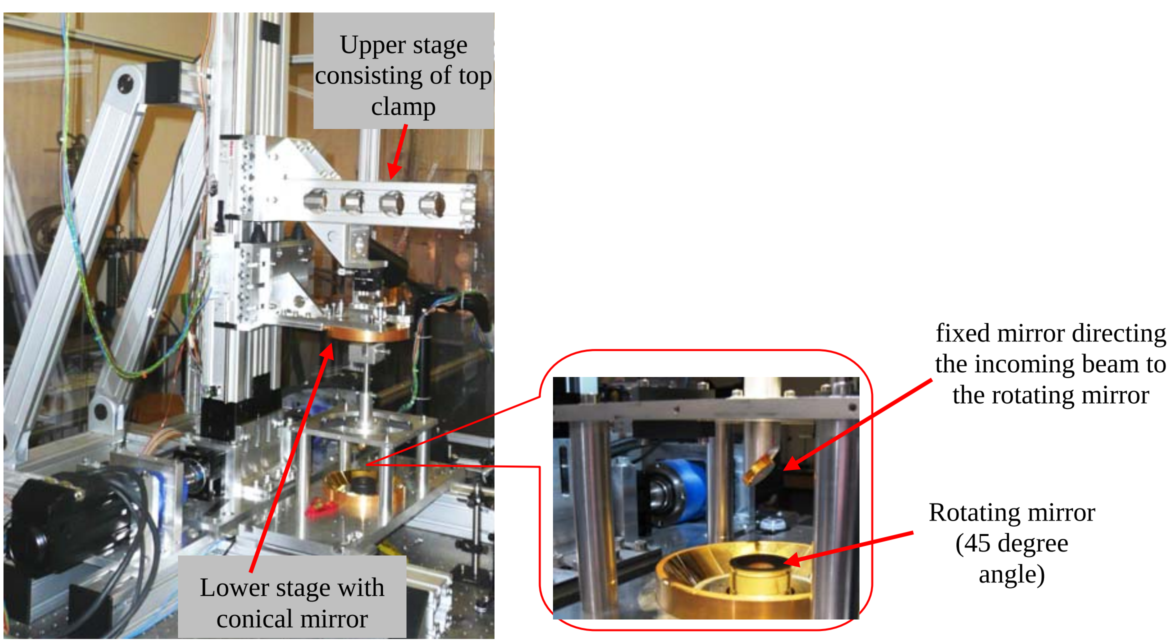
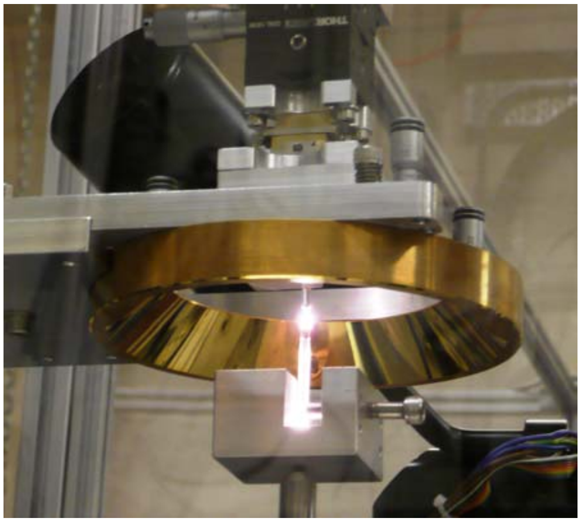


Figure 3 : Schematic of a fibre being pulled after the laser beam is incident upon the input mirror kept at an angle of 45 degrees. This mirror directs the beam onto a rotating mirror (45 degrees) through which the laser beam goes around to the fixed lower conical mirror. This conical mirror deflects the laser towards upper conical mirror which then directs the beam at its centre where the silica stock is clamped.



(a) (b)

Figure 4: Fibre pulling machine set up.



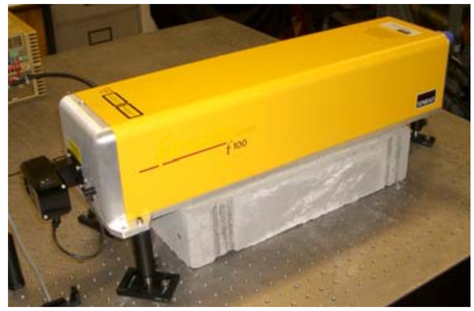
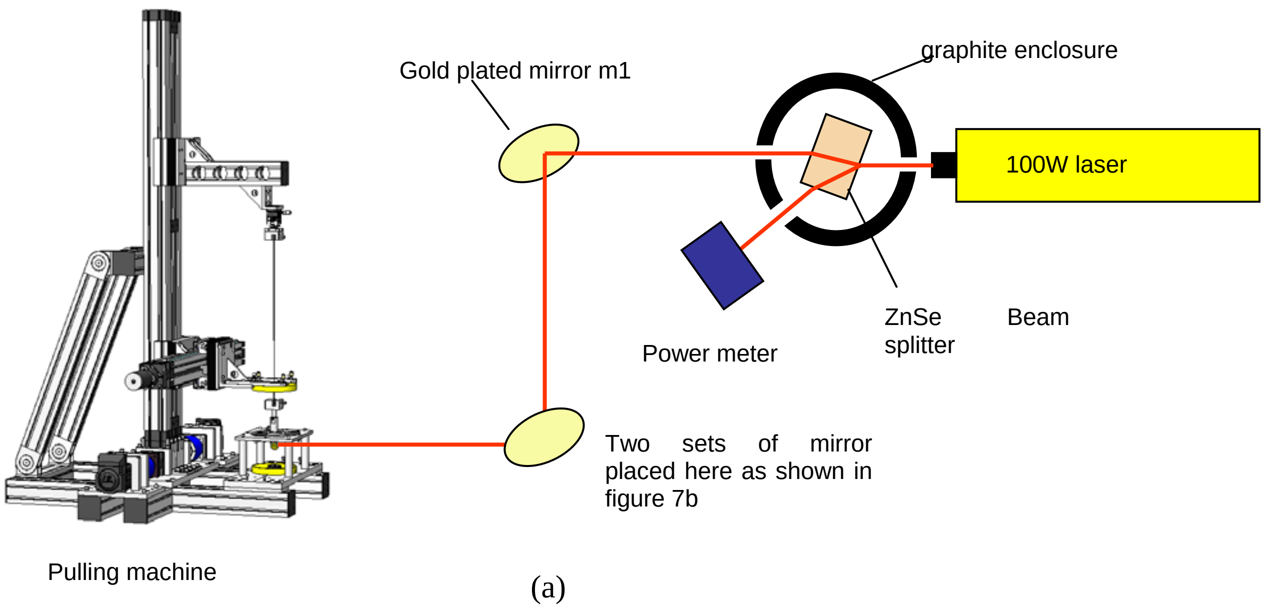


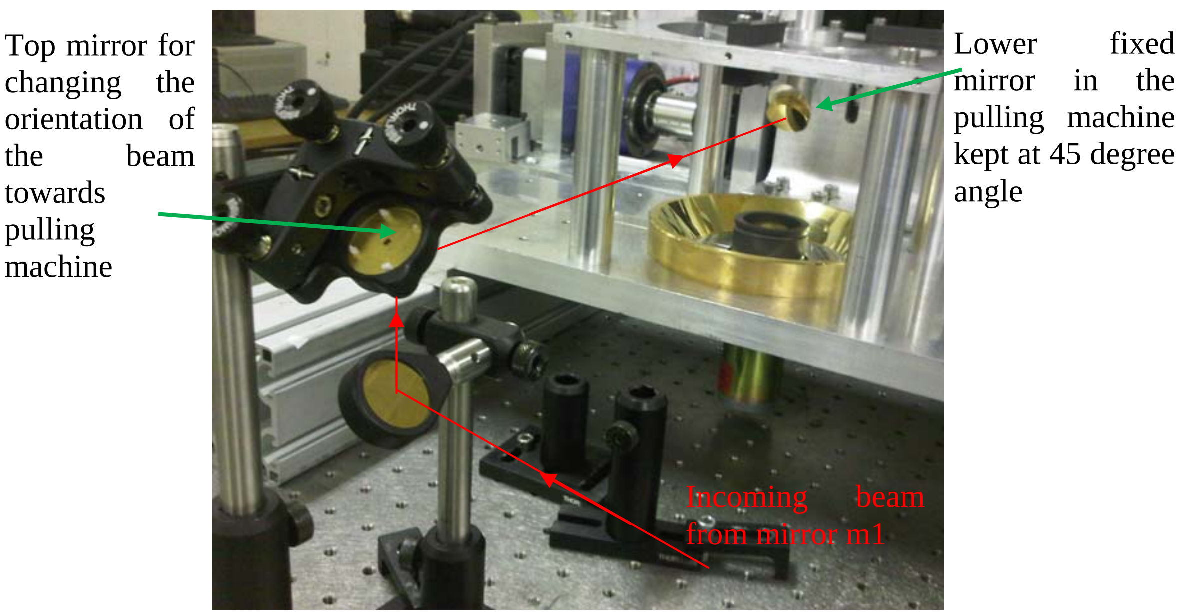
Figure 5(a) Silica stock being heated into a molten state before being pulled into thin fibres. (b) Co_2 laser machine used for heating up the silica stock.

6 Alignment of the laser beam

Before pulling a silica fibre the laser beam should be properly aligned with respect to the pulling machine. A properly aligned system is one in which the laser beam is reflected perpendicularly (angle of incidence + angle of reflection=90) from the surface of the gold plated mirror arrangements and is finally incident upon the centre of the fixed mirror (at 45 degree angle) inside the pulling machine. Figure 7 shows a schematic of the alignment arrangement. The beam fired from the 100 W laser machine is incident upon the ZnSe beam splitter. The beam splitter directs the beam into power meter and also on to the gold platted mirror (m1). A graphite enclosure surrounds the beam splitter to prevent stray laser beam escaping outside. The beam reflects off another mirror (m2) kept parallel to it . At this point there are two sets of mirror facing top and bottom and they help in changing the orientation of the beam direction from where the beam renters into the lower fixed mirror of the pulling machine. Precise alignment of the beam is done by making sure that the laser beam spot is at the centre of the spinning mirror (assuming the top and bottom clamps are exactly centered). A laser pointer (inbuilt in the laser machine) is used to mark the alignment.



(a)



(b)

Figure 7: Schematic of the alignment of the laser beam with respect to the pulling machine

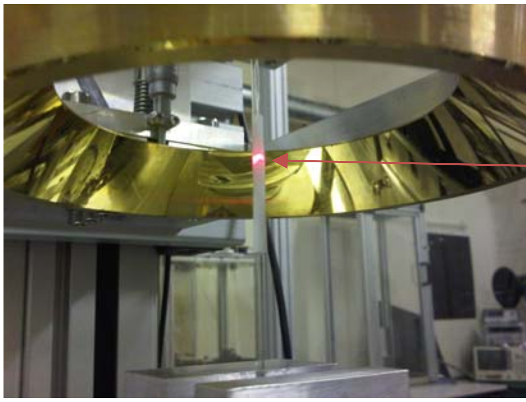


Figure 6 : Laser point incident of the silica stock covered with a white paper to view and adjust the alignment of the incoming beam.

A simple technique used to align the laser beam with the pulling machine is with the help of a silica stock wrapped with a white paper. This will allow the pointer beam to be seen on the silica. The annulus of the laser beam will give an idea of the alignment. If it looks elliptical or at any skewed angle then the gold platted mirror's can be very finely adjusted (using the screws) to improve the beam annulus. Once the pointer beam looks fairly even around the stock then the laser beam can be test fired at full power. The heated silica stock is observed and usually it turns extremely bright and evenly luminous (where the beam hits) when viewed from all the directions. At this time turning the laser off will give the user an idea about the alignment of the clamps too. If the stock develops a kink (or a bent) then it shows that the face of the clamps is not perfectly aligned. The direction of the kink will tell the user which way the top of bottom clamps needs to be moved (usually moving few mm is enough). Then once again the laser beam is fired and the overall alignment is observed. These steps are to be repeated until one is satisfied with the laser beam alignment with the pulling machine, which is essential for a successful fibre pulling.

7 Pulling machine Electronics

The upper and lower carriage has a "hard" and a "soft" limit switch at the outside end of its normal operating range. There is also a similar pair of switches between the carriages to stop them colliding. The soft limit switches are monitored by LabView, which is responsible for setting the velocity to zero (acting as brakes) if they are triggered. The default initial position for the carriages is found by running the lower carriage down until the soft switch below it triggers, and then the upper carriage down until the soft intercarriage switch triggers. The hard limit switches are wired directly to the motor controllers and act as an emergency backup. If they are triggered they cut the power to the motors and the operator needs to manually overide them and use a special LabView program to move the carriages into a safe state (T1000367). Both arms of the pulling machine have magnetic tape linear encoders for sensing position (±0.1 mm resolution). Before each pulling run, the LabView program (T1000367) loads from disk a table of velocity values for the two arms (there is a third column in the table intended for setting the power of the laser, but this feature is currently not utilised.).

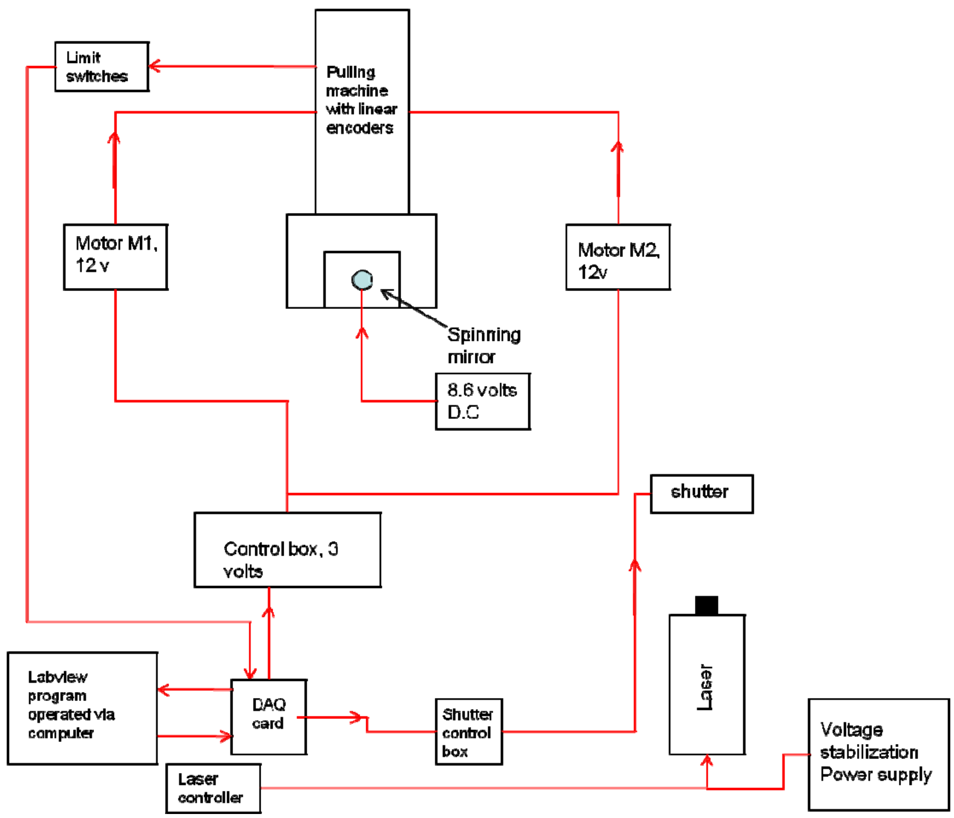


Figure 8: Box diagram giving an overview of pulling machine electronics

An overview of the pulling machine electronics is shown in figure 8. To start the pull (see the next section for detailed fibre pulling procedure), the operator loads the data set, powers up the laser with the shutter closed, waits for it to stabilize and then opens the shutter, which is motorized to allow it to be used from outside the laser safety enclosure. The LabView program detects the shutter opening and begins a countdown, at this time the user needs to observe the silica stock slowly heating up (also keep an eye on stray beam reflections for fire hazards). If within few seconds the silica stock doesn't seem to heat up sufficiently then the laser output has to be switched off immediately (safety buttons pressed to stop motors) and the alignment of the system needs to be checked. At the end of the countdown, the stock is presumed to be molten and the arms are set in motion. As pulses come in from the upper arm encoder, the LabView program steps through the table and sets the velocity outputs accordingly. The length of the resulting fibre is determined by the number of entries in the table. When a requested velocity of zero is encountered, LabView terminates the pull by setting the velocity output to zero (and applying the brakes to the motors). After the pull is completed, the operator undoes the lower clamp and clicks a screen button to raise the upper arm a short distance so the lower end of the fibre is clear of the lower clamp. The operator then removes the fibre and clicks a second screen button to have LabView return the carriages back to their start position as detected from the soft limit switches. The circuit diagram is shown in appendix A.

8 Stock preparation (gluing of fuse ends) and fibre pulling procedure

Silica stock is first cut using a diamond tip cutter to a length of 115 mm (5 mm from each side will go into the metal holster making the effective stock length to 105 mm). Latex gloves should be worn throughout the cleaning and pulling process for cleanliness purposes. The stock is then cleaned with acetone first and then with methanol using cleaning wipes. The stock sample is then glued to metal holsters ('fuse ends' D080404-v1) at both ends. These fuse ends have holes of depth 5 mm and diameter 3.1 mm (approximately). There is also a vent hole for letting out the excess epoxy adhesive which should be wiped off with a cotton bud. The glued stock sample (as shown in figure 9) is then placed into a metal jig (D070551-v2.). This metal jig is placed on a hot plate which is kept at 80 degree Celsius for 2 hours in order to cure the epoxy. The metal holsters are now firmly glued to the silica and are ready to be placed in the clamps of the pulling machine. The stock goes in between the top conical mirror, whose one end is clamped into the upper carriage and the other end at the bottom fixed clamp (as shown in figure 10).

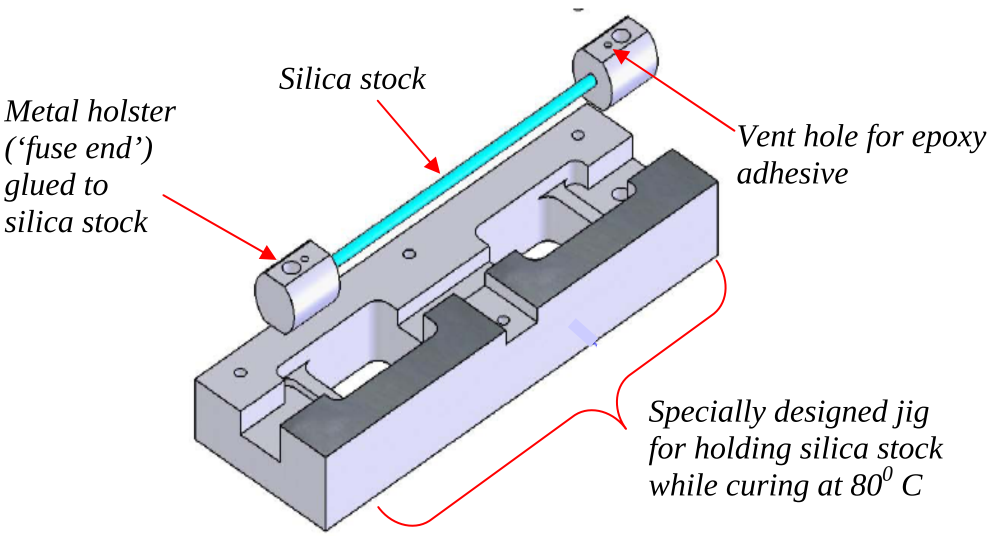


Figure 9: Metal jig holding silica stock having metal holsters at the ends.

Once the silica stock is clamped (and bolted) into the pulling machine it is wiped again with methanol before being laser polished and pulled. Figure 10 shows the clamps which hold the silica stock in the pulling machine. Given below are the steps which need to be followed to laser polish and pull a fibre.

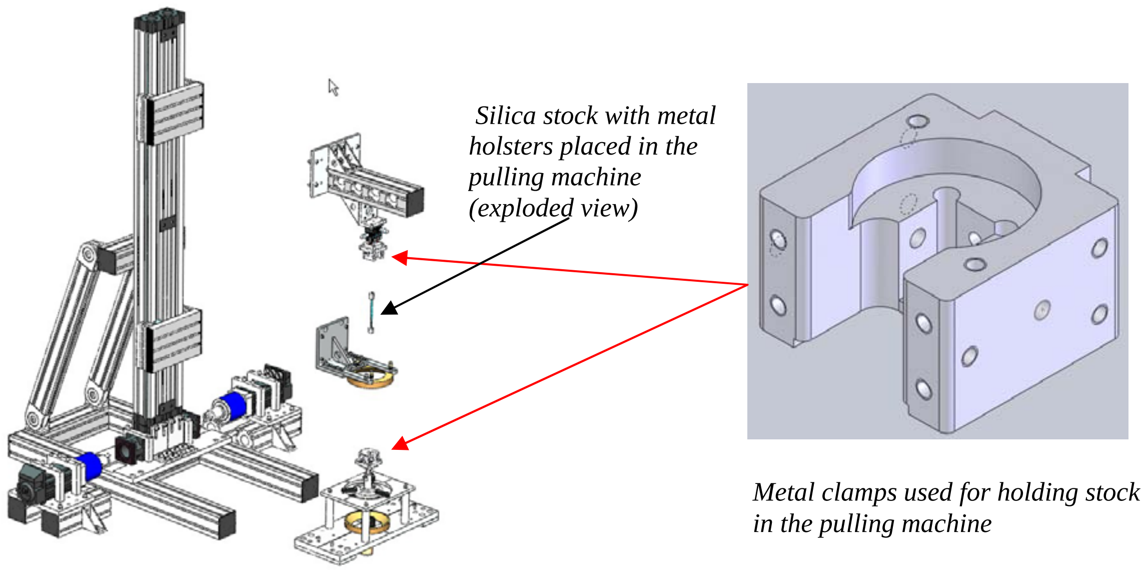


Figure 10: Schematic of the pulling machine showing the metal clamps used for holding the silica stock with metal holsters.

The fibre polishing and pulling process begins with switching on the electronics and control boxes. This includes both the motors, water supply to the laser, the laser itself (after switching on the water supply) and the spinning mirror in the pulling machine. The spinning mirror needs to be kept at 8.6 volts approximately.

The first step is to run the LabView program (T1000367) which is designed for pulling or polishing (and set the speed for polishing) fibres . Figure 11 shows a screen shot of the Labview program once it is opened on a computer monitor.

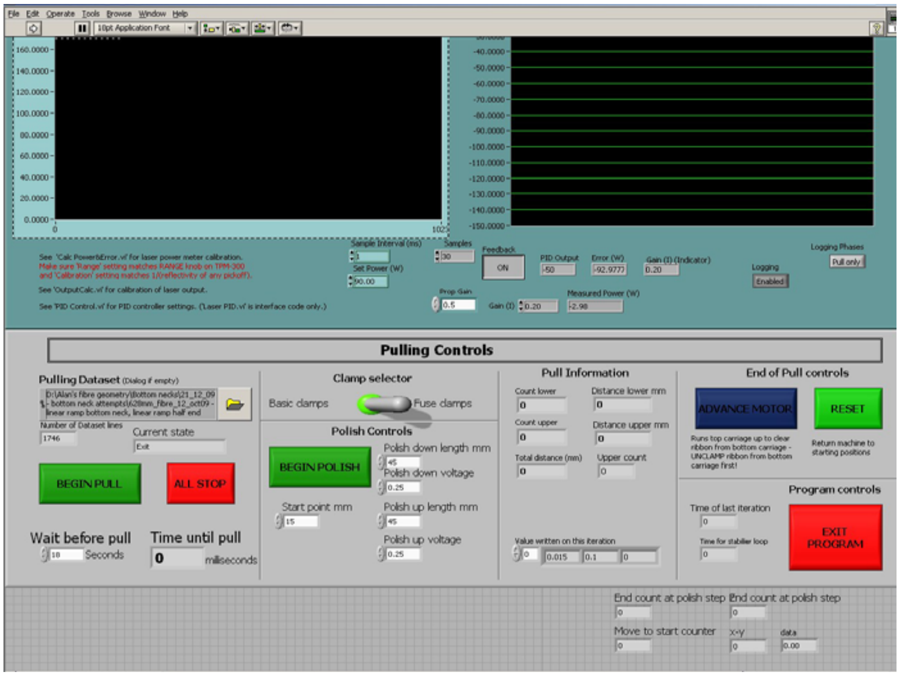


Figure 11: Labview screenshot when the program is initially loaded but not running yet.

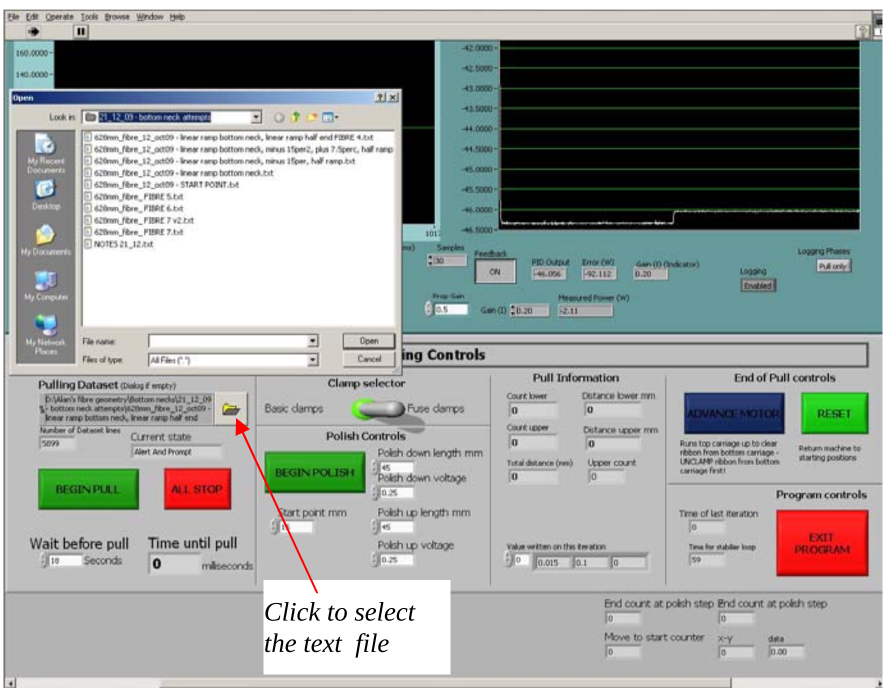


Figure 12: Labview program screenshot showing how to select a file for running a polishing program,

The next step is to select an appropriate file for polishing the fibre (T1000367). This is done by clicking the "pulling datasheet" window as shown in figure 12. Once the file is selected, the "run" icon is clicked (figure 13). At this point the laser key is switched ON and the laser power is increased to 95% (by using the laser controller, rotating the knob increases clockwise or decreases anticlockwise the power, as shown in figure 13).

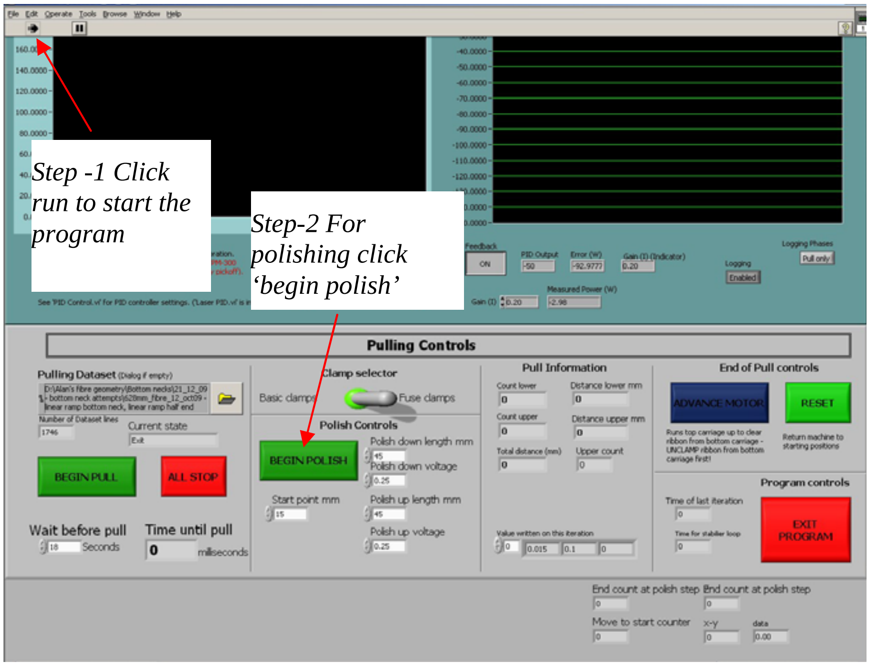


Figure 13: Screenshot showing how to run a Labview program and using the'begin polish' command to start polishing. On the right is the laser controller which has a power variation dial and an ON/OFF switch for the laser.

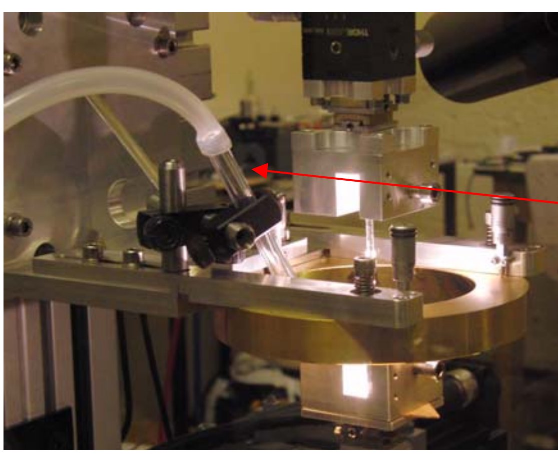


Figure 14: Silica vapor being extracted while polishing/pulling a fibre.

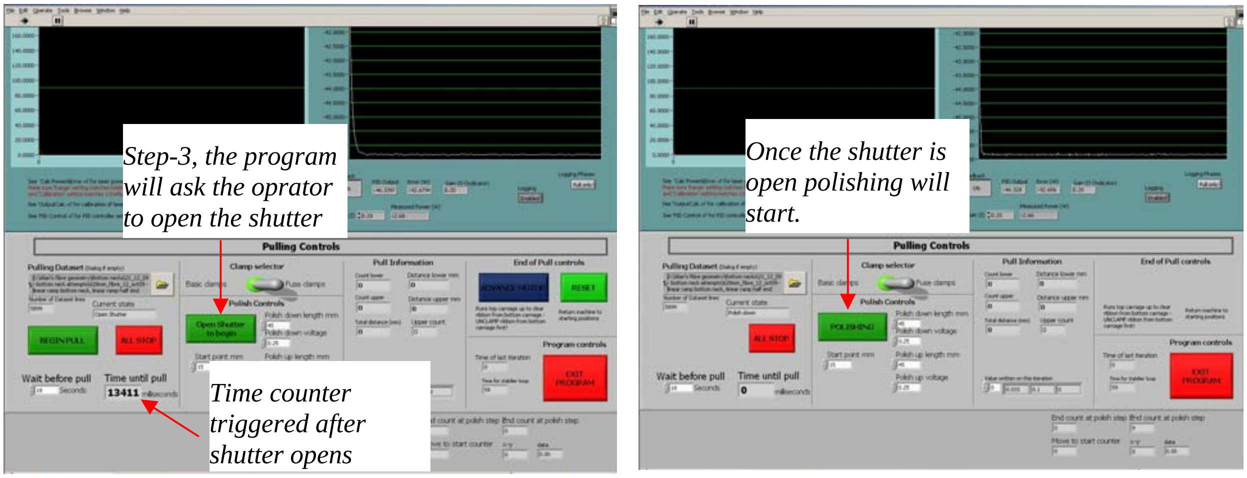


Figure 15: Labview window options for polishing a fibre.

Once the vacuum cleaner is switched on then the laser is fired up (at this point the beam is dumped onto the shutter and is not heating the stock) the “begin polish” command needs to be clicked in labview program. The “begin polish” window will prompt the user to open the mechanical shutter. This will automatically trigger the time countdown (as seen in figure 15). At this point the laser beam will start heating up the silica stock which will start to glow bright. Once the time counter stops, the polishing process will begin. The lower stage will slowly start moving downwards first, polishing the stock on the way. Once the stock is polished down the stage will move in the upwards directions to polish it once again (polishing up and down both helps in making sure that no micro cracks remains in the silica stock). It takes about 20 minutes to polish a 45 mm length of stock in both the direction. All through this process (and even while pulling a fibre) the suction pipe will follow the lower stage, extracting the silica vapor. Figure 14 shows silica vapor extractor in use while polishing/pulling a fibre. A HEPA filtered vacuum cleaner is used for this purpose. On reaching the initial start point position the Labview program will prompt the use to close the shutter (leaving the laser on for stability purposes) to enable the lower stage to move 15 mm downwards. This will set the start point of the fibre and will ensure the entire fibre is pulled within the polished region. On reaching the start point the lower stage will stop and then the actual pulling process needs to be initiated. So once again a new file needs to be selected for pulling fibre (T1000367) followed by clicking the begin pull icon (figure 16). The begin pull icon will prompt the user to open the shutter before starting the countdown timer. At the end of the countdown the upper stage will start pulling the fibre and the lower stage will move slowly downwards to enable continuous feeding of molten silica. Both the stages will come to a standstill once the pulling is complete. At this point the user needs to click on "All Stop" icon and reduce the laser power to zero (keep it on if another fibre needs to pulled, while keeping the shutter closed and dumping the laser beam on the graphite block).

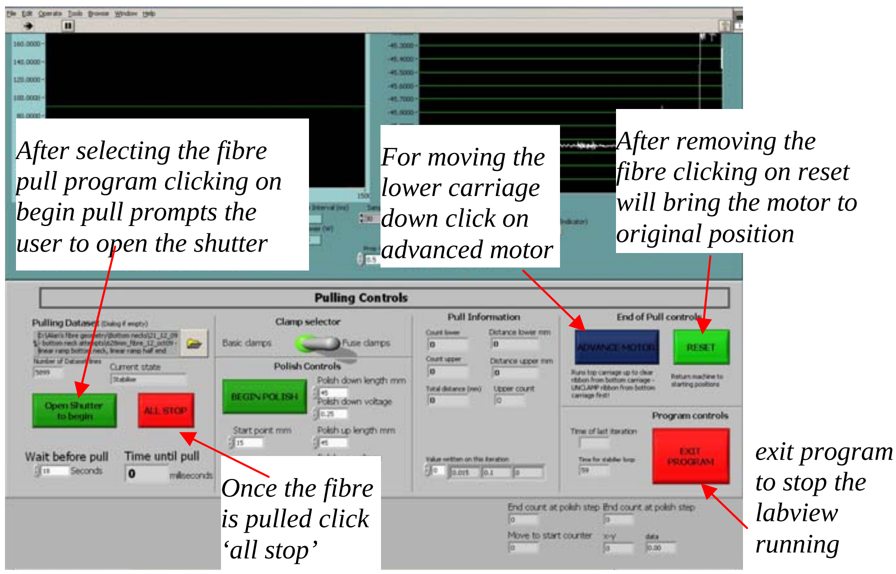


Figure 16: Labview screenshot for pulling a fibre by selecting an appropriate file and clicking begin pull icon (will initiate a countdown counter).

The next section explains the process to successfully remove the fibre from the clamps of the pulling machine without touching it at any point. At first the lower stage clamp is unbolted and then the "advance motor" icon is clicked which will slowly move the lower stage down and finally out the way of the fibre clamps. Then the 'clamp holding brackets' needs to be bolted to the top and bottom clamps. The 'clamp holding brackets' is shown in figure 17.

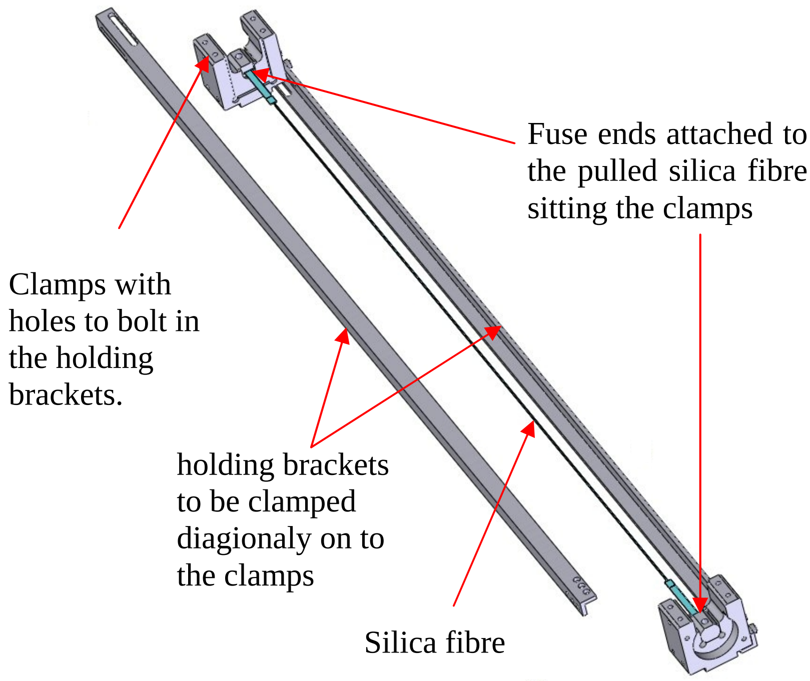


Figure 17: Clamp holding brackets used for removing fibres from the pulling machine. These holders helps safely remove the fibre for storage and can also be directly fitted into the fibre profiler. Also shown is the fibre clamps (metal blocks at the ends of the fibre) which come out along with these holders

The silica fibre can be removed from the pulling machine using the‘clamp holding brackets’ and stored in the fibre racks (DCC number). The “reset” button is then clicked to return both the stages to return to their initial position or start position. Clicking the “exit program” will stop the Labview program from running.

9 Water supply to the laser

A chiller is used to feed a continuous supply of cold water into the CO_2 laser machine. Experiments have shown that there is a strong relationship between the stability of the laser and the quantity of water supplied. Results show that a minimum of 5.8 l/min of water needs to be fed into the laser so as to obtain an optimum performance. However the manual of the laser machine suggest that 9 liters per minute of water supply is desired and hence is implemented. This is explained in detail in the document T060242-00 by M. Barton.

10 Laser safety

The CO_2 laser machine for fabrication and welding of silica fibres contains a Class IV laser with 100 W continuous wave output at wavelength 10.6 micron.

Laser Manufacturer:	Synrad
Model:	Firestar f100
Serial Number:	100027060007

Safety guidelines and practices described in the accompanying Synrad laser manual should be studied carefully and adhered to (DCC LIGO laser safety document).

The Class IV laser operated during operation of this machine can be harmful to both the eyes and the skin. Diffuse reflections of the laser radiation may also be hazardous. The laser emission can also be sufficient to ignite material and to generate harmful radiation or fume hazards by interaction with target materials.

For melting of silica a suitable extraction system is recommended to be used.

The machine should not be operated without first carrying out a risk assessment to determine all of the necessary protective control measures to ensure safe operation.

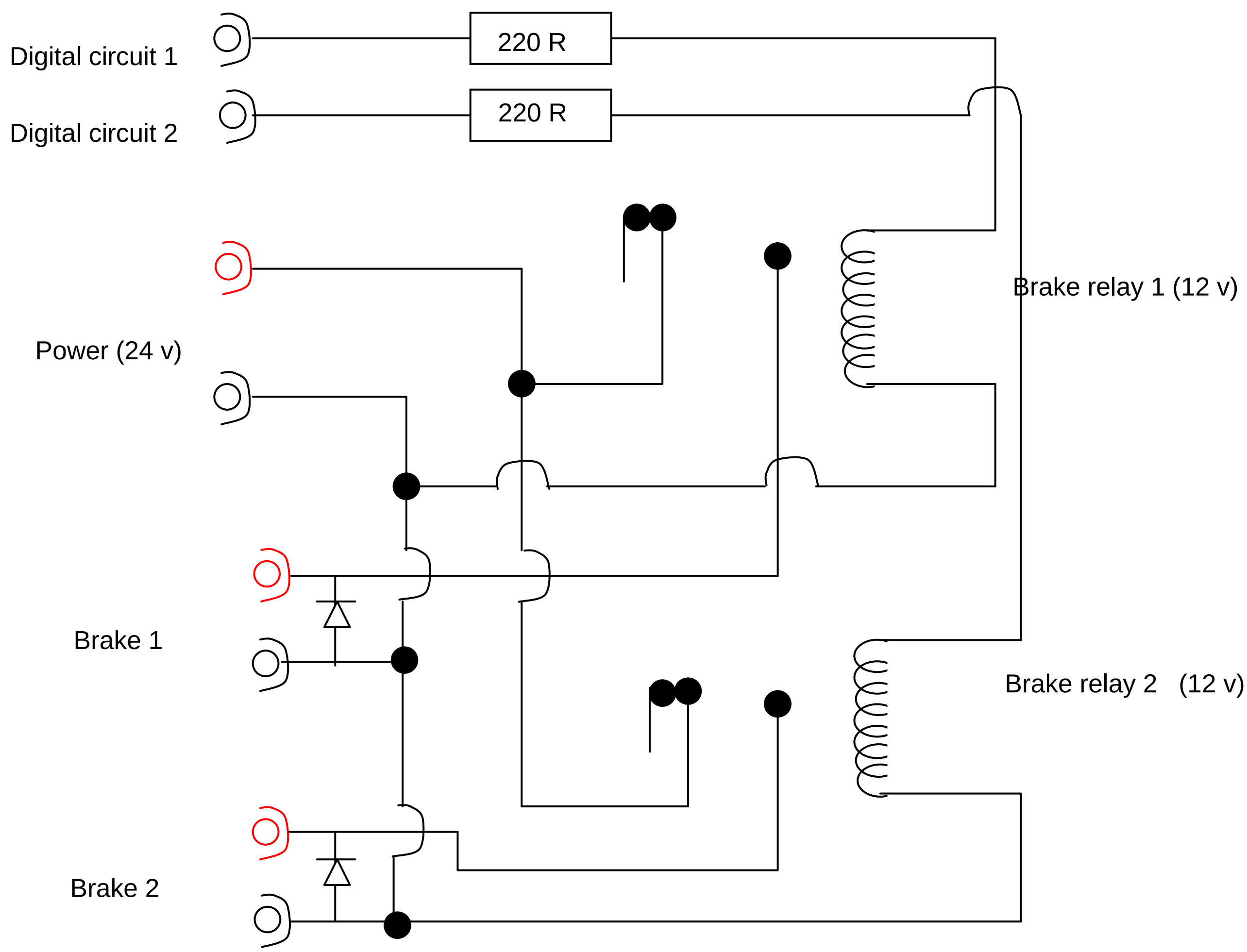
Furthermore, it is recommended that the machine be fully enclosed in a protective enclosure during laser operation.

However, it should be noted that this does not represent a comprehensive list of all safety aspects and must be read in conjunction with the safety standards and procedures in addition to the Synrad f100 Firestar laser operating safety guidelines supplied with the machine.

Appendix A

Brake Relay Box

This box accepts digital signals from the ULTRA 3000 and generates high-power (24 volts) versions for driving the stepper motor brakes.



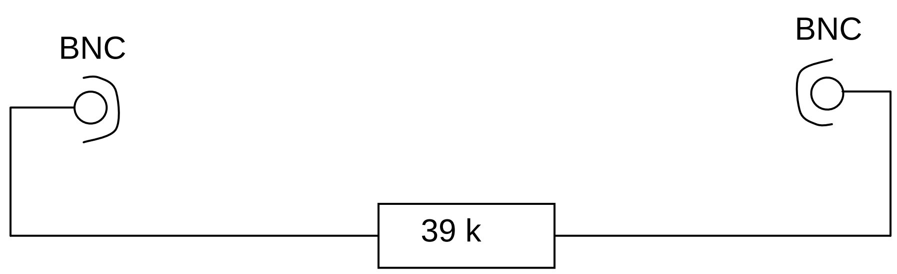
Schematic of the brake relays

The diodes are to prevent arcing due to collapse of the magnetic field in the brake relay coils.

The 220 ohm resistors are to allow operation of 12 V relays from a 24 V supply.

Linear encoder voltage reducer

This box contains exactly one 39K resistor and converts the output of the linear encoder for reading by LabView.

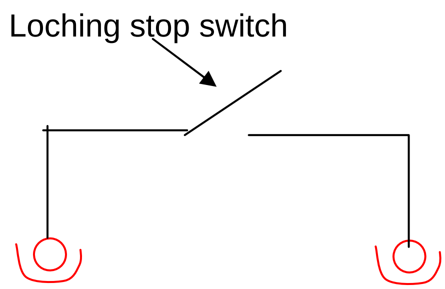


Schematic of linear encoder voltage reducer

The resistor can be very low power – 0.5 W is plenty

Emergency stop switch box

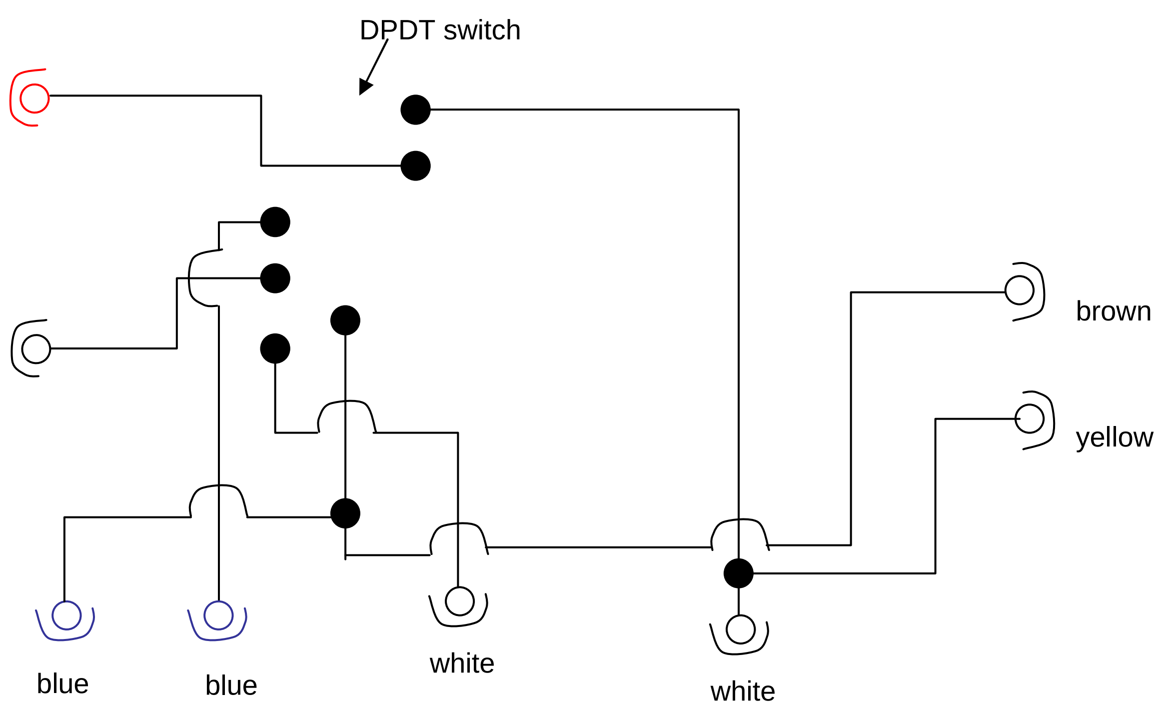
This box needs to be separate and robust because the stop switch is mounted on the top of it for ready access by the operator in an emergency. The switch is N.C. and locks open when pressed.



Schematic of stop switch box

Shutter switch box

This box drives the laser shutter open or closed by sending 12 V DC with the appropriate polarity to a car aerial motor.



Stop relay box

This box enables the stepper motors only if the emergency stop switch and all the limit microswitches are closed. The circuit given below departs from the general principle that the -00 revision of this document is purely descriptive. The real Stop Relay Box had so many obsolete features and dependencies that it would be confusing.