LTP-IV

MANUAL OF OPERATION

Version 1.0

February 14, 2003

Ocean Optics, Inc.

380 Main Street

Dunedin, FL 34698

(727) 733-2447

FAX: (727) 733-3692

Ocean Optics, Inc manufactures the LTP-IV under
license from Brookhaven National Laboratory,
Upton, NY.

Long Trace Profiler

Winner of

1993 R&D 100 Award

Sponsored by R&D Magazine

and

1993 Circle of Excellence Award

Sponsored by Photonics Spectra Magazine

For information or product service, contact Ocean Optics, Inc. at

(727) 733-2447

FAX: (727) 733-3692

E-mail: info@OceanOptics.com
or TAKACS@BNL.GOV

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Chapter 1

Introduction

1.1 Features

The Long Trace Profiler (LTP-IV) is a non-contact optical profiling instrument, designed to measure the absolute surface figure and mid-frequency errors of flat, spherical, and aspherical surfaces of up to 1500 mm in length or diameter. The LTP-IV system is comprised of an optical head mounted onto a linear servomotor carriage that traverses a 1.5-meter long stainless steel beam chosen for its dimensional stability. A novel beam-splitting arrangement produces two pairs of probe beams from a 635 nm solid-state laser source mounted in the optical head. One set of beams is scanned over the surface under test, while the other is sent to the optical table as a reference to remove any pitch errors from the traveling optical head. A closed-loop DC linear servo motor system with a high-resolution linear encoder provides accurate position information as the carriage is moved along the beam.

A key feature of the LTP-IV is the wide range of surface shapes that it can measure. Long-radius surfaces with kilometer curvatures, aspherical surfaces, cylindrical surfaces -- all are easily aligned to and measured by the LTP-IV. There is no need for special large calibrated reference surfaces or corrective null optics, as would be required for conventional interferometric measurement of such surfaces. This ease of alignment and great flexibility is a result of the unique LTP-IV optical system. A Unique temperature independent phase plate is used to generate the test and reference probe beams, which are imaged by the optical system onto an array detector. The interference patterns produced on the detector are a direct measure of the local slope of the surface under test, from which the height profile can be derived by integration. The RMS slope error in each measurement point is typically less than 0.5 microradians [0.1 arc seconds], with an absolute RMS accuracy capability in the height profile of less than 50 nm over the full 1.5 meter travel range. The direct slope-measuring capability of the LTP-IV has proven to be very valuable in the measurement and correction of mid-frequency surface errors.

Another unique feature of the LTP-IV is its ability to measure absolute surface shape by correcting for dynamic angular errors in the optical head during the traversal of the carriage along the ceramic beam, without the need for costly auxiliary reference surfaces or previously-calibrated standards. The reference arm beams are reflected from a small stationary mirror on the optical table and return through the optical system along the same path as the beams from the surface under test arm. Both systematic and random angular errors in the optical head orientation affect the test and reference beams equally, but with opposite sign, so that the sum of the two signals contains only the absolute surface shape information.

1.2 Environmental Concerns

Precision measurement at the nanometer and microradian level on meter-long optical components requires an approach to optical testing that is not usually found in the typical laboratory environment. Environmental stability is usually the limiting factor in the performance of the LTP as an absolute measuring machine. In order to reach the limit imposed by various noise sources, one must be very careful about maintaining an extremely stable local environment for the LTP and the optic to be measured. This includes:

1) Maintaining a stable, constant and uniform temperature in the environs of the system so that the optic under study does not change dimensionally. Although the LTP itself is virtually temperature insensitive, noise can be produced by turbulence in the air where the laser beam is propagating.

2) Mounting the LTP on a very stiff and stable surface.

3) Locating the unit in a quiet, vibration-free area.

4) Insuring that the surface under test is at least as stable as the LTP.

A stable thermal environment is critical to meaningful precision measurements. For example, the thermal expansion coefficient of Aluminum is approximately 2.5 parts in 10^5, so a thermal drift of only 0.1 C between the two vertical supports is enough to produce a change in tilt angle of the crossbeam on the order of 2.5 microradians. Over the length of a 1-meter surface, this can be interpreted as sag of 2.5 micrometer, which is a significant error compared to the system's ultimate absolute error capability of 50 nanometers. Fortunately, the metal components are extremely well coupled and it would be difficult to generate such transients during a measurement in a normal thermally quiet environment.

The "health" of the LTP measurement system can be gauged in a number of ways. Two of the most common and useful methods are by checking the repeatability of a measurement and by doing a "stability scan." If one does successive scans over a surface without changing the measurement parameters, one would expect the results to be nearly the same each time. A problem with the system will usually manifest itself by systematic changes in each successive profile. This method is sensitive to the low frequency, long period thermal drifts that affect the measurement of the absolute surface radius of curvature. The stability scan, on the other hand, does not move the optical head, but rather sits in one place taking data to simulate a real scan. The stability scan is useful to determine if the detector is functioning properly, or to determine the system static noise level, since the carriage does not move during this scan.

1.3 Measurable Surfaces

1.3.1 Intrinsic Surface Properties

LTP measurements can be done only on specular surfaces, that is, only on surfaces that are polished and smooth and return a significant signal back to the detector. The rule of thumb is that if you can see a reflection of some kind in a surface, then it should be possible to measure it with the LTP. The standard LTP optical head can measure surfaces with no more than a 30 milliradian change in slope along the scan length. This translates into a surface radius of not less than 30 meters for a 1 meter scan length, or a surface radius of not less than 1.6 meters for a 50 mm scan length. There is no restriction on the value of the minor radius, i.e. the radius of the surface in the direction transverse to the scan direction. A cylinder lens compensates for curvature in this direction by focusing the beam onto the detector in the transverse direction without affecting the measurement capability in the longitudinal direction. The LTP can measure convex surfaces as easily as it can measure concave surfaces. Another consideration is that the line segment over which the surface profile is measured must have its surface normal entirely in the plane of incidence determined by the laser beam direction and the scan direction vector. In other words, the surface must not have excessive "twist", otherwise the reflected beam may walk off the top or bottom of the detector array. Never-the-less, the cylindrical lens can compensate over a quite large curvature range.

1.3.2 Mounting Stability

As mentioned in the previous section, it is extremely important to insure that the surface under test is mounted in a stable configuration during the test. Seemingly insignificant differences between test set-ups can produce significant changes in the test results. Mounting constraints are extremely important in attempting to make precision absolute curvature measurements. If the type of mount is not specified, the results are meaningless. Also, handling the object prior to the measurement may introduce transient thermal deformations that will take time to die away. Many quite thick flat mirrors can be observed to be concave by the LTP when mounted only at the ends. The weight of the mirror itself causes the curvature.

1.3.3 Transparent Substrates

Since the effective depth of field of the measurement beam is very large, owing to the collimated common-path nature of the probe beam, special precautions must be taken when measuring uncoated, transparent substrates, to insure that back surface reflections do not produce spurious interference with the test or reference beams anywhere during the traverse across the surface. An object with a fine-ground back surface will not present a problem, since the transmitted beam is diffusely reflected. Most surfaces usually have a slight wedge angle, which may be sufficient to skew the beam reflected from the back surface so that it misses the detector. This is true if the wedge is in the direction transverse to the scan. If the wedge is parallel to scan direction, there is a problem. Spherical surfaces with polished flat rear surfaces will usually produce spurious interference when the laser beam is scanning near the middle of the surface, when the front and rear surfaces are nearly parallel. The most effective way to deal with these back surface reflections is to paint a solid dark line on the back surface along the scan direction. This tends to mitigate the reflection from the air-glass interface by providing contact with a material with a closer matching index of refraction and by absorbing the beam that is transmitted.

Chapter 2

System Overview

The information in this chapter is intended to provide an overview of the LTP's subsystems and to enable the user to switch on the system from a cold start condition. It is intended only to familiarize one with some of the terminology and essential procedures required preparing the system for making measurements. It is not intended to be an exhaustive list of procedures to cover all operating eventualities, but rather deals only with those things that need to be done to prepare the LTP system for making measurements after a complete shutdown has occurred. One assumption erroneously made is that the solid-state laser has to be left on at all times and to be allowed to reach thermal equilibrium with its surroundings. There is so little heat from this laser and such a huge heat sink, that no precautions are necessary. You can just turn on the laser by plugging in the optical head USB port and immediately take measurement. You can also leave it on at all times if you wish.

2.1 LTP-IV Subsystem Components

connector = ▭ All connectors have only one position that fits.

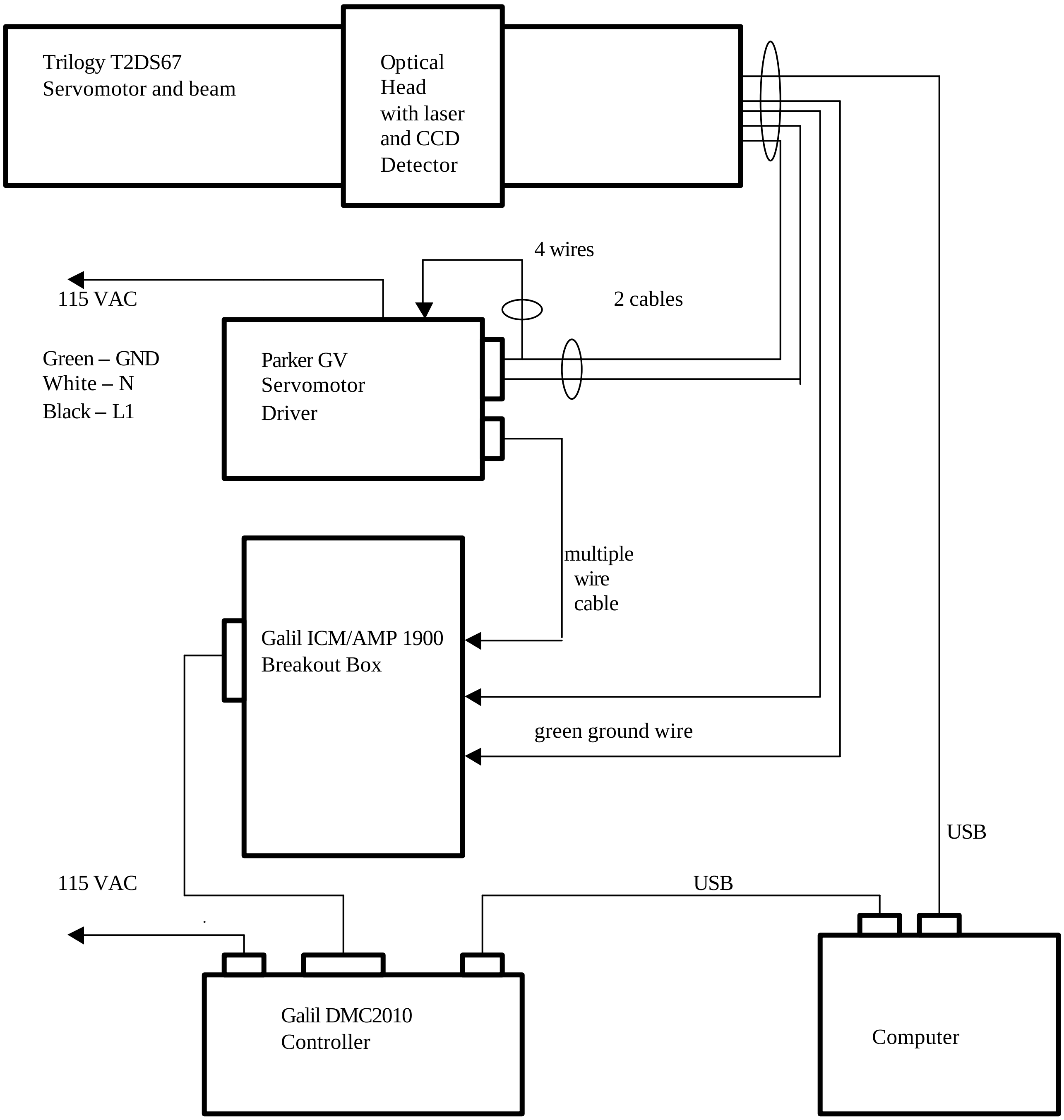


figure 2.1 - Block diagram of the LTP-IV system configuration

Figure 2.1 shows the basic configuration of the components of the LTP-IV system, and how they are connected. The LTP-IV is comprised of 3 main subsystems: the computer, the CCD detector/laser/optical head, and the linear servomotor system. The computer operates both the servo system and the optical head through its USB port. Thus, any computer that can operate the software can be used. Many people use portable PCs. The detector is an Ocean Optics USB2000 spectrometer board. The active region of the CCD linear array detector consists 2048 pixels, each 14 microns wide by 200 microns high. Data is taken and the 2048 pixels are read out through the USB port as a 16 bit number in about 13 ms. Since this is so fast, it allows ample time at each measurement position to perform time based signal averaging as the usual integration time is only 3 ms. In addition, the whole CCD system is so small, it takes up negligible space in the optical head. A special narrow band optical filter is placed on the CCD so that the system is sensitive to the laser, but rejects ambient light. Of special note is that both the CCD detection system and the laser together use only 1 watt of power. This power is easily dissipated in the mass of the optical head and has no effect on the system.

The computer controls movement of the servomotor by instructing the Galil controller to go to some point. This is done through the USB port where it uses almost no resources of the computer. The Galil controller has been programmed with a script that instructs the Parker motor driver to accelerate the motor, move toward a solution and decelerate to that solution. The Galil controller also monitors the linear encoder to determine the progress of the motor. Upon reaching a solution, the Galil controller reports back to the computer that the motor is in position. The computer then takes the appropriate number of samples from the CCD detector and then instructs the Galil controller to move to another position.

2.2 Startup Procedure

The following procedure assume that the system has been previously installed and commissioned. These instructions are sufficient to allow a user to start up the system from a "cold start" condition, where all components have been switched off.

1. Turn on power to the Galil and Parker units. The servomotor will be activated in a locked position.

2. Turn on the computer. If a portable, make sure the two USB connectors are plugged in.

3. Start the OOILTP software.

4. You are ready to take data. Most users begin by turning off the motor from the screen and positioning the optic in the beam by manually moving the optical head.

2.3 Optics Board Details

2.3.1 Component Diagrams

Figs. 2.2 and 2.3 show the configuration of the optical components on the optics board. Fig. 2.2 is a representation of the actual layout of the optical and mechanical components on the optics board. Fig. 2.3 is a schematic optical diagram identifying the major components.

2.3.2 Optical Path Tour

The laser beam first goes through a phase plate that splits the beam into two identical beams, one being retarded by 180 degrees. The next element is a fixed polarizer followed by a rotating polarizer. This amplitude adjuster is necessary when measuring, so as not to saturate the detector. The beam then enters a rotating half wave retardation plate that adjusts the amplitude of sample beam vs. the reference beam.

The beams next go through a polarizing beamsplitter cube. This cube splits the beam again into two sets, one set exits the cube vertically and heads down toward the surface under test (SUT), the other exits horizontally and goes through a penta prism to hit the reference mirror on the same surface as the SUT. These beams are nominally circularly polarized after exiting the polarizing cube which has 1/4 wave plates next to the exit faces. The intensity between the two beams is adjusted by rotating the retardation plate to obtain equal intensity in the test and reference fringe patterns. This will need to be adjusted depending on the reflectivity of the surface under test. Both probe beams return upon reflection to pass back through the polarizing cube, and are then brought to a focus at the detector, via a Fourier transform lens. Each beam pair focuses down such that the two beams that make up the pair interfere with each other. For a 30 mrad acceptance angle, the FT lens must have a quite long focal length, so the beams are folded by mirrors before being brought to a focus on the CCD diode array.

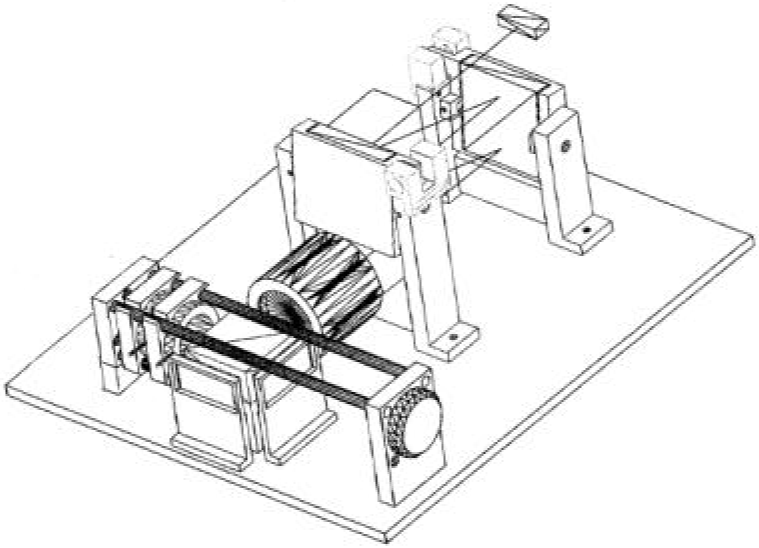


Figure 2.2 Optical Layout

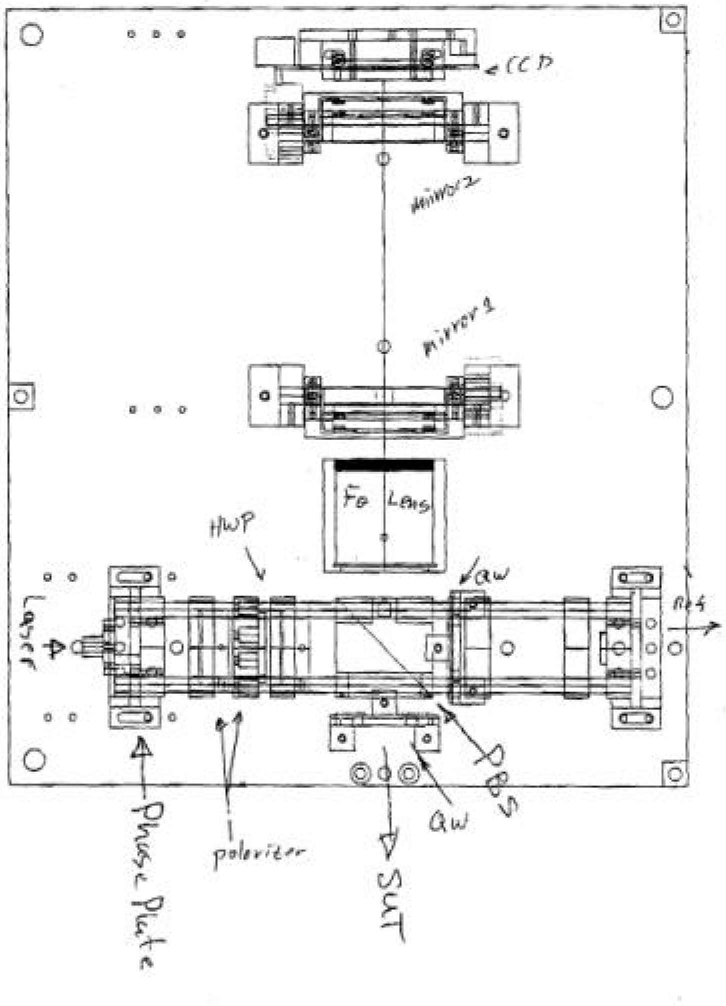


Fig. 2.3 - Optical schematic of LTP system, identifying major components in the optical head. PBS = polarizing beam splitter; HW = half-wave retardation plate; QW = quarter wave retardation plate; F? lens = Fourier transform lens. The rotating polarizer adjusts total light intensity. The half-wave plate (HWP) adjusts the relative intensity between the test and reference arms.

Chapter 3

Basic Tour through the OOILTP Software

The LTP software package for the LTP IV and earlier LTP system upgrades consists of the new OOILTP operating software. The new software controls all scanning and analysis functions. Included in the software is a powerful scripting system that allows many different types of LTP configurations and scanning options. The scripting language is Java Script, which is a simple straightforward programming language.

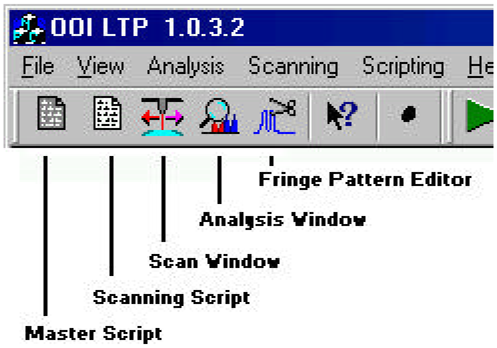
This chapter will give a basic overview of the software and the next chapter will give a step-by-step walk -through of how to setup a scan and then analyze the data.

The new software has changed considerably. If you have used the previous versions of the software please take time and read through the next two chapters. If this is the first time using any LTP software please take the time to read these next chapters as well.

Before moving on please take note of the words in *Italics* these refer to the actual names of the windows and buttons in the software.

3.1 OOILTP Main Menu

Figure 3.1 OOILTP Menus



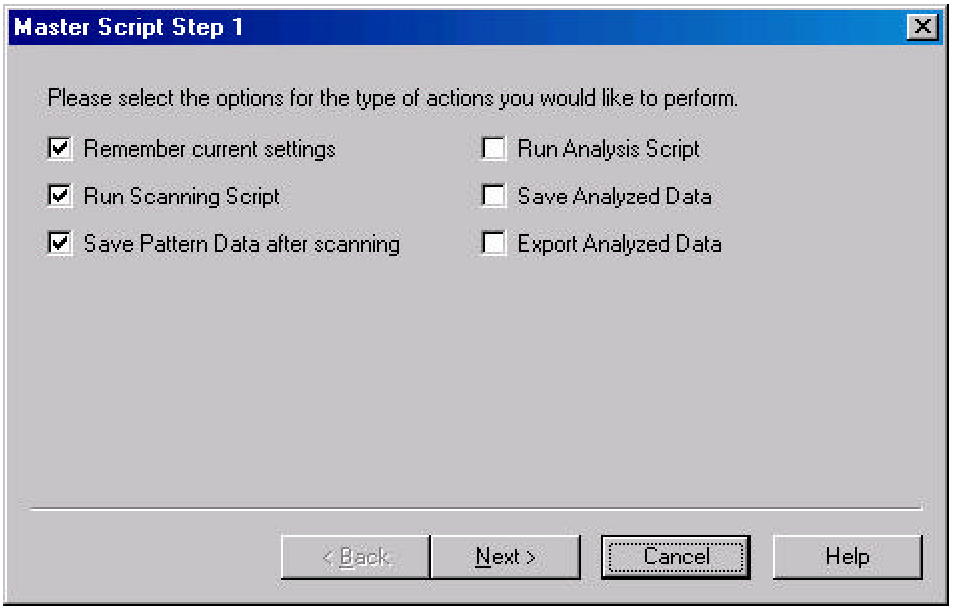
We will start first by describing the program menus. Figure 3.1 is a screen shot of OOILTP program menus. The *File Menu* allows you to select the Dlls that will be used for scanning and motor control. The Dll system is a new feature in LTP software. The Dll system allows the software to interface with multiple motor types, allowing for a wide variety of LTP designs to all use the same software. Before you begin using the software you will have to select the Dlls you will use. This will be explained more in the Chapter 4.

The *View Menu* contains options related to the user interface and not related to the LTP operation. The *Analysis Menu* has several menu options related to the Analysis of the LTP data, the *Scanning Menu* has all the menu options related to scanning, the *Scripting Menu* has all of the script operations, and the *Help Menu* has the normal help information.

The important features to note here are the tool bar buttons. These buttons allow you to switch between the different modes of the software. The *Master Script* button will open the master script setup window. Master Scripts are used to control the overall operation of the software. For example the software can take multiple scans and automatically analyze the data and then save it. The *Scanning Script* window allows for making scripts that will control scanning. Several generic types of scans are included or you can create your own custom script. Scripts will be discussed more in the next section. The *Scan Window* is where the actual scanning takes place. And the *Analysis window* is where the analysis of the data takes place. Finally the *Fringe Pattern Editor* allows you do look at the raw data and make changes to or fix problems with it.

3.2 Master Script

Figure 3.2



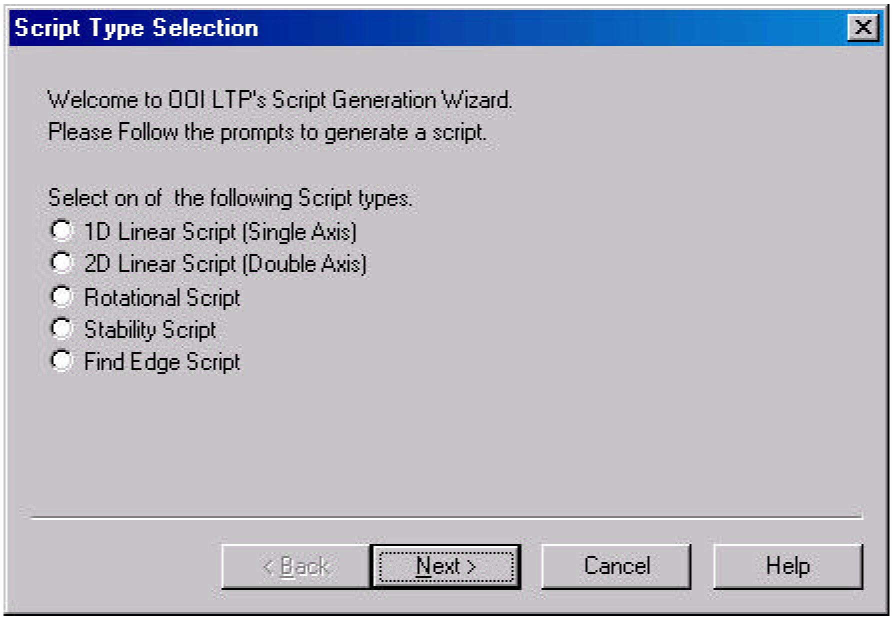
Please select the options for the type of actions you would like to perform.

☑ Remember current settings
☑ Run Scanning Script
☑ Save Pattern Data after scanning
☐ Run Analysis Script
☐ Save Analyzed Data
☐ Export Analyzed Data

The master script wizard allows you to create a script that will control most aspects of the software. You can find more about the Master Script in the LTP Software help file.

3.3 Scanning Script

Figure 3.3



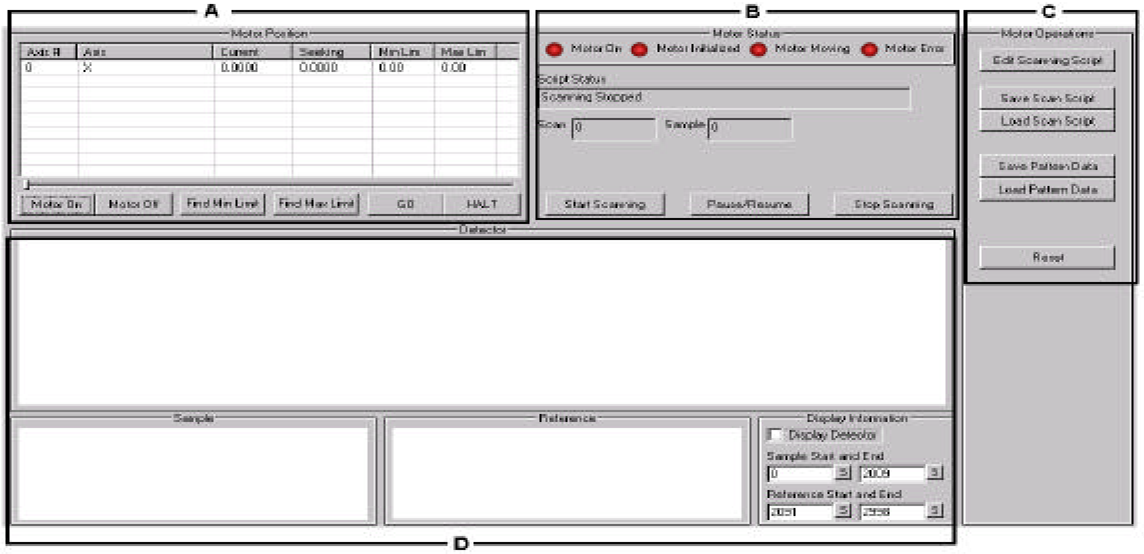
Welcome to OOI LTP's Script Generation Wizard.
Please Follow the prompts to generate a script.

Select on of the following Script types.
○ 1D Linear Script (Single Axis)
○ 2D Linear Script (Double Axis)
○ Rotational Script
○ Stability Script
○ Find Edge Script

The scanning script wizard lets you create several types of scanning scripts. These scripts control the movement of the motor and the acquisition of slope data from the LTP head. Specifics of the Scanning Script can be found in the LTP Software help file. An example of the scripting system can also be found in Chapter 4.

3.4 Scan Window

Figure 3.4



Axis #	Axis	Current	Seeking	Min Lim	Max Lim
0	X	0.0000	0.0000	0.00	0.00

Script Status: Scanning Stopped

Scan: 0 Sample: 0

☐ Display Detector

Sample Start and End: 0 2009

Reference Start and End: 2051 2558

The scan window is where all the scanning functions takes place. The scan window is broken up into several parts.

Section A displays information about the motor. It displays the axes that it is controlling, the current positions on those axes and where they have been instructed to seek to. The motor state can be controlled from this area as well with the Motor On/Off buttons. To set a position for the motor to seek you double click the axis that you want to move, though most LTPS are a single axis only. A dialog box asking for the coordinates pops up. Enter your coordinates in meters and then with the axis still highlighted hit the go button. This starts the motor for that axis in motion. To stop have the axis selected and click the halt button. The slider below the axes gives the approximate position of the axis selected. If the axis is currently half way along its range the slider will be half way. You can click and drag this slider and it will roughly set a new seek position. Then click the Go button.

The limits are the valid ranges for movement of the motor axes. Use the *Find Min / Max Limit* buttons to set the limits. These functions are setup to automatically find the minimum and maximum of the axis.

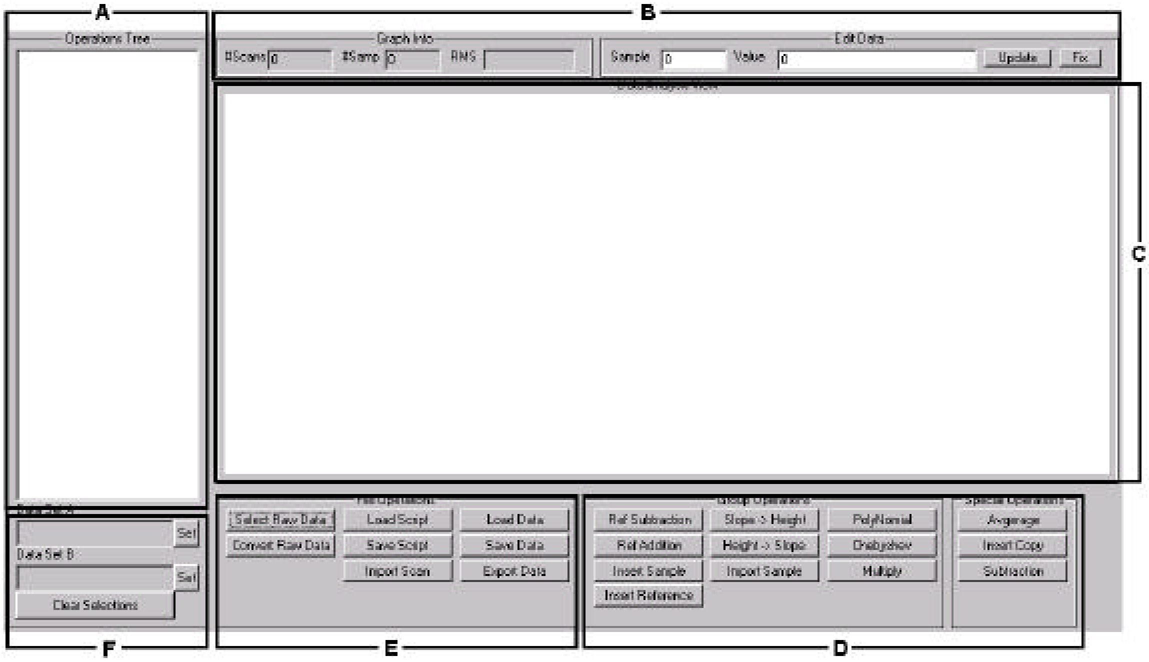
Section B is where the scan status and motor status is displayed along with the buttons that control the actual scanning process. The Motor status section displays the different motor statuses, *On*, *Initialized*, *Moving* and *Error.* An off state is a Red dot and an active state is a Green dot. The current script status is displayed in the *Script Status window*. The *Scan window* displays the current scan and the *Sample window* shows the current sample. To start a script you click the *Start Scanning* button, similarly you click the *Pause/Resume* button to pause and resume a scan and the *Stop* scanning will abort the scan after the next sample is taken.

Section C is the script control section. You can view and edit the currently loaded script by clicking the *Edit Scanning Script* button. You can save the script to a file by clicking the *Save Scan Script* button or load one by clicking the *Load Scan Script* button. The *Save Pattern Data* button will let you save the fringe data that has been acquired in its sampled format rather than after it has been converted to slope data. The *Load Pattern Data* lets you load a pattern file that you have previously saved. This is similar to clicking the *Select Raw Data* button in the *Analysis window* described in the next section.

The last **Section D,** displays the data acquired from the LTP head. Based upon the mode of operation the large window in the top will display the raw detector data, the slope data or nothing at all. These options can be selected under the *Scanning Options*. In *Detector* mode it displays the raw data from the LTP head showing the fringe patterns. In this mode you can tell the ranges of the sample and reference patterns by the blue bar for sample and red bar for reference background. In *Auto Slope* mode the slope is calculated after each sample and is graphed as the scan progresses. And in the *Fast Scan* mode nothing is drawn, which can speed up the scanning process depending on the speed of the computer doing the scanning. In the lower right section there are several options, the first is the *Display Detector* this will start the scanning of the LTP head and display the raw data in the *Detector Window*. The next boxes are the ranges for the sample and reference patterns. More information can be found on the pattern ranges in the LTP software help file or the example in chapter 4.

3.5 Analysis Window

Figure 3.5



The analysis window is the most complicated part of the LTP software, because of its power and flexibility. After a scan has finished you will come to this window to perform the analysis.

In **Section E** are the buttons controlling the conversion and other data functions of the analysis window. If you have just finished a scan clicking on the *Convert Raw Data* button will convert your scanned data to slope. It will be display in the *Data Analysis view* (section C). The data will also be displayed in a tree form in the *Operations Tree* (section A). Also in section E are the buttons that load and save analysis scripts and loading and saving of data. For more detailed information see the LTP Software help file.

Section F has some special data selection windows that are explained in more detail in the LTP Software help file.

Section B displays the number of scans in the converted data and the number of samples per scan. It also shows the RMS value of the currently selected sample displayed in the *Data Analysis view* window (section C). You can move the cursor by clicking in the *Data Analysis view window*. A cursor line will appear and the sample number will be displayed in the *Sample window* in the section B. The current value at the sample is displayed in the *Value window*. You can enter a new value here and click the *Update* button to save that value. The *Fix* button will average the two samples to either side of the cursor and assign the cursor the averaged value. Beware that this will change the slope profile data.

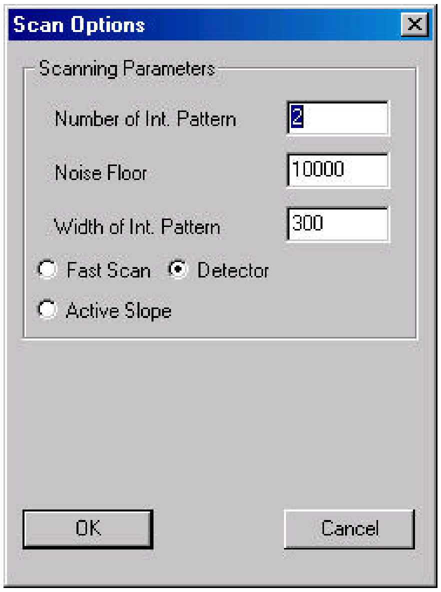
Section A is the *Operations Tree*. All the scans and their data nodes are displayed here. More detailed information can be found in the LTP Software help.

Section D is where are all the analysis operations that can be performed. These range from reference subtractions to polynomial fits and slope to height conversions. More detailed information on what each operation does and its use can be found in the LTP Software help file.

Section C is the main display, the selected node data is displayed here or during conversion the fringe patterns are shown.

3.6 Scanning Options

Figure 3.6



Scan Options

Scanning Parameters

Number of Int. Pattern: 2

Noise Floor: 10000

Width of Int. Pattern: 300

○ Fast Scan ● Detector

○ Active Slope

The Scan options window contains various scanning options used by the LTP software. The options can be brought up by clicking the appropriate toolbar button or from the *Scanning menu* by selecting *Options*.

The *Number of Int. Pattern* is the number of interference patterns that are to be used. The current values are either 1 for sample only or 2 for reference and sample.

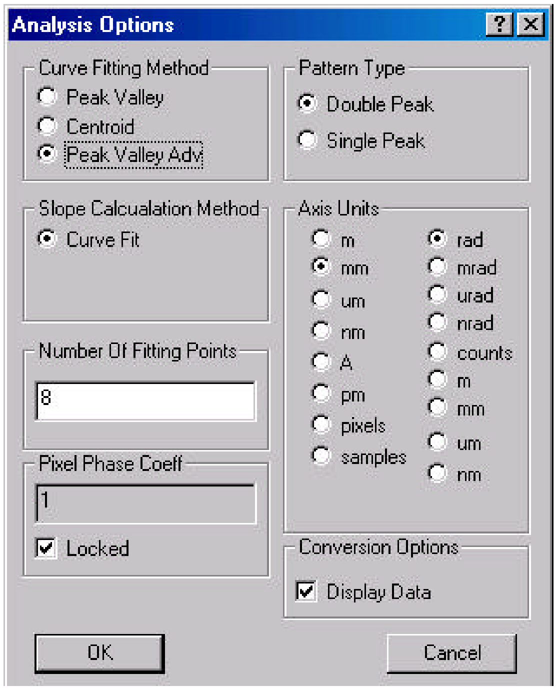
The *Noise Floor* is a level used by the fringe pattern algorithm. The start of the fringe pattern is defined as the first point that the fringe pattern rises above the noise floor. In the *Scanning window* the noise floor is the gray horizontal bar in the sample and reference windows.

The *Width of Int. Pattern* is the number of data points sampled after the start of the fringe pattern. This should be slightly larger than the width of the fringe pattern. 300 points have been found to work in most situations.

The last set of options are the display options *Fast Scan, Detector, Active Slope*. When *Fast Scan* is selected no data is drawn to the detector window during the scan. This helps to speed up a scan whe he computer's graphics are slow. *Detector* mode allows the display of raw data from the LTP head during a scan. And *Active Slope* calculates the slope after each sample and graphs the slope as the scan progresses.

3.7 Analysis Options

Figure 3.7



Curve Fitting Method
○ Peak Valley
○ Centroid
● Peak Valley Adv

Pattern Type
● Double Peak
○ Single Peak

Slope Calcualation Method
● Curve Fit

Axis Units
○ m
● mm
○ um
○ nm
○ A
○ pm
○ pixels
○ samples
● rad
○ mrad
○ urad
○ nrad
○ counts
○ m
○ mm
○ um
○ nm

Number Of Fitting Points
8

Pixel Phase Coeff
1
☑ Locked

Conversion Options
☑ Display Data

The Analysis Options window contains the various scanning options used by the LTP software. The options can be brought up by clicking the appropriate toolbar button or from the *Analysis menu* by selecting *Options.*

In *Curve Fitting Method* the techniques used to fit a curve to the fringe pattern are chosen. More information can be found in the LTP Software help file. Peak Valley Advanced is normally used.

The *Pattern type* describes the type of fringe patterns *double peak* or *single peak*.

There is only one slope calculation method at the moment, *Curve Fit*.

The *Axis units* allow the user to choose the units of the display in the Analysis window. The first column is the X axis or position, the second is the slope.

The *Number of Fitting Points* is the number of points along the fringe pattern that will be used to fit the curve for a slope calculation.

The *Pixel Phase Coeff* is the conversion factor from detector pixels to slope. This is your system calibration. Changing this once the LTP is calibrated will make your analysis results wrong. You must uncheck the locked box before you are able to change this calibration.

The *Conversion options Display Data* allows the fringe patterns to be displayed as the data is converted in the analysis window. Un-checking this can decrease the time taken to convert data to slope.

Chapter 4

A Step by Step Example of the OOILTP Software

4.1 Starting The Program

When starting the software for the first time you must select your motor and scanner dll. To select the scanning dll select from the file menu *Select Scanner Dll*. A windows Open File dialog box will open and you can select your scanner dll. The default is called **OOIScanner.dll** and is located in the same directory you installed OOILTP. Select it and choose open.

Repeat with the motor dll. The correct dll should be located in the same directory as the scanner dll. Please check your software documentation for your custom dll name.

After selecting both dlls close the software and restart it. You should not get any error messages. Look in the text output window of the software and you should see some information related to the dlls.

4.2 Configuring Options

First we will configure the scanning options. Click the *Scanning options* button on the toolbar. This will open the scanning options window. For a description of these settings see section 3.6 or the LTP software help file. First we will set the number of interference patterns. If you are just using a sample pattern and no reference then set *Number of Int. Pattern* to 1. If you have a reference then set it to 2.

We will have to come back and adjust *Noise Floor* once we look at the signal on the detector. This value will vary depending on the integration time of the detector and the surface type you are measuring.

The *Width of Int. Pattern* is by default 80 but this is usually too small. A better value is 300. You can determine the actual width later when we are ready to scan and come back here to change it. Being too large is not a problem as long as the range does not overlap at any point with the reference fringe pattern.

For scan type we will set *Detector*, we can look at the raw data coming from the LTP head. Click OK.

Now we will configure the *Analysis Options*. Click the Analysis options button on the toolbar. This will open the analysis options window. For a description of these settings see section 3.7 or the LTP software help file.

First we will pick *Peak Valley Adv* method for finding the minimum value of the fringe pattern. We will leave it on a double peak setting, as this should be the way a normal LTP head is operated. Set the *Number of Fitting Points* to 15. Leave the Axis units on mm for the first column and rad for the second column. You should have a calibration coefficient value that was given to you during the setup process of the LTP. If it isn't entered under the *Pixel Phase Coeff* then enter it. You have to uncheck the Locked box before you can change the value. We will also leave the *Display Data* option checked. Click Ok.

4.3 Motor Setup

Click the scanning window button to open the scanning window. You can check the currently loaded script by clicking the Edit Scanning Script button.

Before we start scanning lets get our motor set up. At this point all the motor equipment should be turned on. If it was off turn, it on restart the program, and follow the instructions below.

1. Turn the *Motor On*. (If it is not already)
2. Run the *Find Min Limit* button. It will prompt you to move the motor close to the home position. If you cannot move it manually just press ok anyway.
3. The motor will now seek to the home position and reset its counter to zero.
4. When it finishes do the same except with the *Find Max Limit*. Slide it close to the far end if possible.

5. When finished you should have Min Limit set to zero and Max limit set your maximum range. You only have to run the *Find Max Limit* once unless your range changes for some mechanical reason. You will need to run the *Find Min Limit* each the motor controllers are reset or turned off and on again.

You may need to find the edges of your optic. You can do this by turning the motor off and moving the carriage to the end of the optic. Then turn the motor back on and record this position. Turn the motor off and move it to the other end of the optic and record that position. You will use these positions when creating your script.

4.4 Scanner Setup

Before we observe the ccd detector output we need to set up its characteristics. From the toolbar select the scanner setup button . This will open the scanner setup window. The standard LTP scanner has several options. To configure the Scanner follow these instructions.

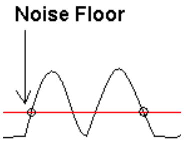
1. Set the integration time to 5 ms.
2. Set the number of averages to 1.
3. Set the boxcar to 0.
4. Leave the channel set to 1.
5. The FFT option will allow you to adjust the FFT filtering width. FFT of 0 means no filtering while 1000 means cut out the top 1000 spatial frequencies. There are a total of 2048 frequencies. Typical settings are around 1600 - 1800.
6. Now Click the Setup HW button. This opens the Configure Hardware setup window. The standard LTP IV package includes a USB detector.
    a. Under Spectrometer Type you want to select S2000/USB2000.
    b. Under the A/D Converter type set it to USB2000.
    c. You can select the detectors serial number if it is listed under the USB Serial number. Normally this will only be done during system setup.
    d. Click OK.
7. Click Ok

Now lets check the ccd detector. You should be on the *Scanning window*. To view the detector check the *Display Detector* box in the lower right hand corner. You should now see the data coming from the LTP head in the Detector Window. If not, make sure your laser is on and the optic is aligned correctly.

For the next steps I will assume you are using both reference and sample patterns and both are visible in the detector window. We now need to set the ranges for the sample and reference. To set the ranges follow the instructions below.

1. First turn the *Motor Off*. Now you can move the carriage by hand.
2. Slide the carriage and notice which direction the sample pattern moves. Move it so the pattern moves to the left as far as it will go.
3. Place the cursor at the left side of the pattern by clicking with the mouse in the detector window.
4. A red line should appear at that point. This will be our start of the sample range.
5. Click the *S* button next to the *Sample Start window* in the lower right side of the scan window.
6. The pixel number of the cursor will be stored there.
7. Repeat this by moving the carriage and thus the fringe pattern to the other far side. This time click the *S* button next to the *Sample End window*.
8. Now place the cursor on each side of the reference pattern and repeat for the *Reference Start* and *End*.
9. Once you have the ends indexed you should see the full range of the sample pattern contained within the *blue range* and the reference pattern contained in the *red range*.

Now we must adjust the noise floor value. To do this we need to look in the *Sample* and *Reference* windows. The gray bar is the noise floor. Remember the intersection of the noise floor and the fringe pattern is where we start sampling. You will want to adjust the noise floor to be above the detector noise so that the fringe pattern rises above the noise level on the first peak and falls below it on the second peak.



It does not matter if the valley falls above or below the noise floor. Also, you can now determine the width of the pattern by placing the cursor on the left side of a pattern and record pixel location and then place the cursor on the right, The difference is the width in pixels of the pattern. Remember its ok to have this value a little larger than the actual pattern width. After entering the pattern width you will probably never need to change it.

We are now ready to create a scanning script.

4.5 Creating the Scanning Script

To create a scan script we will use the script wizard. Click the create script button on the toolbar. This will open the Script Type Selection window. There are several types of scripts that we can choose from. Rather than choosing the a simpler script we will choose a little more advanced option.

1. Click the 2D Linear script, then click next. Most of the LTP IV's will only have a single axis of motion. Some custom configurations may have multiple axes, but we can also use the 2D linear scan to take multiple scans on a single axis.
2. First we must select our axes, select your scan axis now. Look at the diagram to get an idea of the difference between the scan and the sample axes. The sample axis is the axis upon which slope is measured. Click Next.
3. Next, we enter the scan start position. Since we are going to first do an averaging scan, you can just enter 0 here. Click Next.
4. Now we enter the end scan position. Once again since we are going to do an averaging scan we can enter 0 here as well. Click Next
5. Now we will enter the number of scans to take. In a normal scan the number of scans would be determined by the (Scan End - Scan Start) / Scan Step. But since we are going to do a average scan the only value used is the Scan Step. So, lets enter 2 for now. We will actually take 3 scans, 0,1,2. And when we analyze the data we will see three separate scans listed. Make sure to check the Average mode box. Click Next.
6. Now we will select our sample axis. This may or may not be the same axis as the scan axis. Click Next.
7. Now enter the starting position to start our sampling. This should be in meters. Click Next.
8. Enter the end position in meters.

9. Now enter the number of steps to take between those two points. Click Next.
10. You will now have a display of the created script. You could save it at this point by clicking the *Save Script* button. Click *Finish* to use the script we just made.

4.6 Scanning

Now that we have all the hardware setup and our script created we are ready to begin a scan. Make sure the motor is on and operating properly. You can check to make sure you have a script loaded by checking the *Edit Scanning Script*. To start the scan you push the *Start Scanning* button.

The motor should begin moving the carriage to the start of the optic to scan and then proceed down the optic sample by sample. If you used we just created, when the motor gets to the end, it will go back to the beginning of the optic and repeat that scan 3 times. If you had a second axis and did not choose average mode then the other axis would make a move and after one scan the motor would move back to the start and begin again.

You can watch the progression of the scan by noting the *Scan number* and *Sample number* in the Scripting status section. You can also *Stop* and *Pause/Resume* the scan.

When the scan finishes we have two options. We can save the pattern data by clicking the *Save Pattern Data* button. This saves the fringe pattern data only. You can then continue on to Data analysis with or without saving.

4.7 Analysis

Click the *Analysis* button to open the *Analysis window*. Since we have just completed a scan we can hit the *Convert Raw Data* button to generate a slope curve from the raw data. If we had not just performed a scan then we would need to click the *Select Raw Data* button and open a raw data file. This is how you would analyze data that has been saved with *Save Pattern Data* under the *Scanning Window*.

If you have the *Display Data* option checked in the *Analysis Options* window then you will see the sample and fringe patterns overlaid and the fitted curve laid on top. The sample is dark blue; the sample curve is light blue. The reference is dark red; the reference curve is light red.

When the conversion process is finished you will see in the left side in the *Operations Tree* the scans we just analyzed. Each scan has a *Sample Node*, a *Reference Node*, and a *Data node*. All operations take place on the data node. The data node is a data stack. When you do an operation, the last operation on the data node stack is processed by the selected operation and then the results are added on top of the data node stack. You can look back at any previous level but all operations are performed on the top node. You can remove operations only from the top.

We will now review some basic operations and use of the *Operations Tree*. By clicking on the Scan header you will notice the icon change from LTP to SEL. When the icon is SEL then that node is selected. Only selected nodes will be included when performing operations. You can also right click on the Scan and choose select all. This will select all scans. So lets begin by processing some data.

1. Right click on scan 0 and choose select all.
2. Now, lets insert a reference correction. This will take the sample and subtract from it the reference. Click the *Ref Subtraction* button. In a scan this corrects for any carriage pitch errors.
3. Notice that the data node changes from empty to REF CORRECT.
4. Now, lets subtract out a polynomial of zero order. Click *Polynomial* and enter 0.
5. Click now on the POLYNOMIAL node. When you click on a node the data is displayed in the Data Analysis View. See how the data is now placed around zero. We have removed the 0 order or a_0 offset value. If you also click the + sign next to the POLYNOMIAL node you will see some more information about that operation. Many nodes have extra information available. Also, if you click on the Degree node you can see the curve that was calculated and then subtracted.
6. Notice how they are stacking. Try clicking back on the REF CORRECT node to see that all the data is still present.

7. Now lets average all of our scans. The Average operation is a special Operation meaning its results are placed in the Temp node. Click the *Average* button.
8. Now the Temp Node has AVERAGE in it, this is the average off all the scans that are selected.
9. Now lets subtract the average from all our scans. The subtraction is also a special operation. It will subtract the node you have selected in the *Data Set A* from all selected nodes. So select the AVERAGE node under temp and the click the *Set* button next to the *Data Set A* window. It now says AVERAGE, meaning it has that node selected.
10. Now click the *Subtraction* button. Notice another node is added on called SUBTRACTION.

We now have a measure of the stability of the scans on the mirror during the many repeated scans. A scattered set of values might indicate the noise of the environment. A noticeable bias versus time might indicate a temperature change of the optic.

That is just a sample of what can be done in the analysis section. Another key feature is the ability to save analysis scripts. By clicking the *Save Script* button you can save an Analysis script you have just performed. The script can then be loaded and will perform all the operations that are saved on any data set that has the same number of scans. To load a script click *Load Script*.

You can also save the data by clicking *Save Data*. Save data will save the Sample, Reference and the data node results to a file. If you load this data you will loose operations stack. So, if you want to be able to examine the stack again you will want to save the pattern data and the analysis script and reload both in order to recreate the results. Saving data is useful if you only care about the final results.

For an explanation of the many other operations available please check the LTP software help file.

4.8 Conclusion

This chapter has been a step-by-step example of how to operate and run the OOILTP software. More information can be found in the LTP software help file that is located in the same directory as the program. Also inside the program you can place the mouse over an item and press the F1 key and it will display help about the item and its use.

Appendix 1

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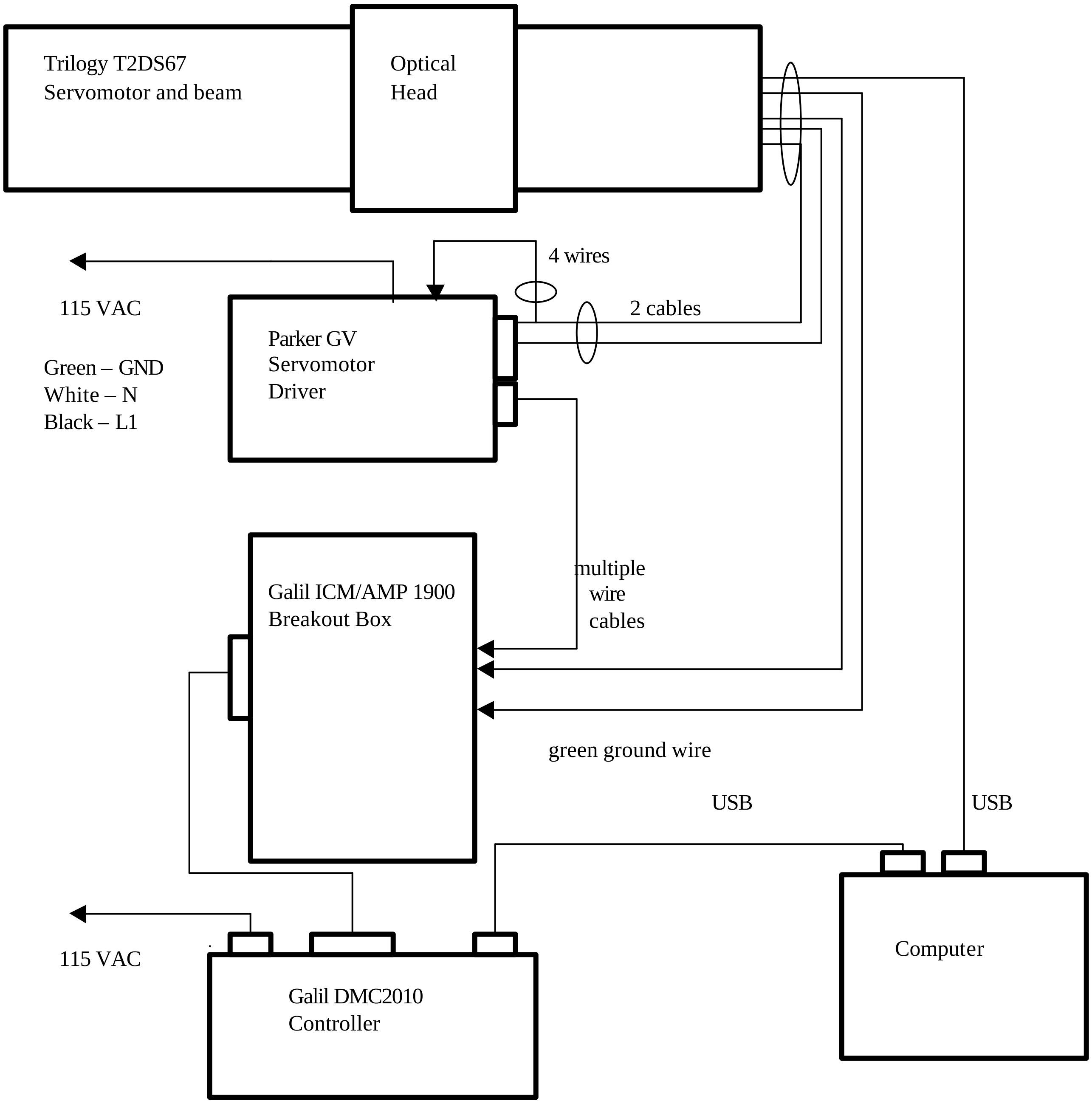
Appendix 2

Motor Interface Control Box Wiring Diagram

connector = ▭ All connectors have only one position that fits.



1. Multiple wire cable from Parker GV to Galil Breakout box

Wire color	to	Description
Brown	32	MOCMDX
Brown on White	17	GND
Grey on White	17	GND
Violet on White	40	AMPENX
Blue on Grey	36	+5 VDC
Orange	83	+MAX
Orange on White	84	-MAX
Blue	85	+MBX
Blue on White	86	-MBX
Yellow	87	+INX
Yellow on White	88	-INX

2. Jumper in Galil breakout box

41 (LSCOM) to 54 (+5 VDC) This is a pull up for limit switches.

3. Renishaw Encoder – cable from Trilogy beam to Galil breakout box

Wire color	to	Description
Green	51	HOMEX
BLUE	52	RLSX
Brown	53	FLSX
Wire color	to	Description
White	55	GND
Black	111	+12 VDC

4. Ground wire from Trilogy Beam to Galil Breakout Box

Attach green wire to ground lug.

5. 4 wires that exit dual cable connector from the Trilogy Beam to the Parker GV

Wire Color	Connection
White	GND
Orange	W
Brown	V
Red	U

In some cables, the White wire is replaced by a Black wire.

Appendix 3

Safety Features of the LTP-IV

1. Electrical

All equipment is CE and/or UL approved.

All power supplies are isolated by the servo drive and computer manufacturers and grounded.

The optical head mounted CCD detector and the solid-state laser are powered only through the computer USB bus (5 volts DC 500 ma maximum available). The LTP-IV uses 175 ma.

All systems are grounded to the mains as well as the optical table.

2. Thermal

Less than 200 watts of heat are generated (usually about 50 watts). It is distributed over the surface of 2 instrument cases.

3. Moving Carriage

There are many safety features built into the system:

a) Cut-off switches at each end of the carriage.

b) Over-speed cut-off by the controller. (Speed limit)

c) Resistance cut-off. That is, the system must come to a solution very quickly or the command is aborted and the motor is turned off. One test is to hold the carriage to keep it from moving and watch the system shut down. This keeps someone from pinching a finger or getting anything tangled in the system.

d) Maximum movement is usually no more that 1 cm per second. Scans are slower. All movements have acceleration and deceleration.

e) If the appropriate laser peaks are not present, the system cannot start a data scan. If it is moving and the scan signal disappears, the system stops. Thus, if a person gets near the operation and interrupts one of the 2 beams, the system stops.

4. Laser safety

The LTPIV uses a class IIIA, 4 mW laser diode with output at 635 nm. This probe laser output is attenuated by at least 50% because of internal polarizers. Because the detector is extremely sensitive, normal operation is less than 100 uW. All laser output is in the downward direction toward the optical table. One weak beam exits to the left (or right in some systems) near the surface of the carriage and is directed downward at its end.