THE LZR2000® AND LASER FEEDBACK SYSTEM

OPERATION & TECHNICAL MANUAL

P/N: EDU169 (V1.0)

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If you should have any questions about the LZR2000 and/or comments regarding the documentation, please refer to Aerotech online at:
http://www.aerotechinc.com.

For your convenience, a product registration form is available at our web site.

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The LZR2000 and Laser Feedback System
Operations and Technical Manual Revision History:

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PREFACE

This section gives you an overview of topics covered in each of the sections of this manual as well as conventions used in this manual. The LZR2000 Operation & Technical Manual contains information on the following topics:

CHAPTER 1: INTRODUCTION

This chapter contains an overview of the LZR2000 Laser Feedback System. Included is a general description of the components of the system, options and accessories, a typical system diagram, an application overview, proper handling and storage techniques, and laser safety and precautionary statements. This chapter also contains information to familiarize the operator with the terminology associated with interferometry, the laser head and optics. In addition, Chapter 1 introduces special temperature, humidity and pressure considerations for maintaining accurate measurements.

CHAPTER 2: UNPACKING AND INSPECTING THE SYSTEM

This chapter explains the proper procedures for unpacking and inspecting the components of the LZR2000 system prior to their installation.

CHAPTER 3: GETTING STARTED, A FIRST LOOK

This chapter provides the user with a first look at the LZR2000 Laser Feedback System. It is designed to briefly walk the user through the setup and use of a simple measurement application.

CHAPTER 4: PHYSICAL SETUP OF THE LASER HEAD AND TRIPOD

This chapter explains how to install the laser including choosing a location, mounting, positioning, making electrical connections, aligning the optics, accuracy and possible error sources.

CHAPTER 5: LINEAR DISPLACEMENT AND VELOCITY MEASUREMENTS

This chapter explains how to position and setup the required optical components of the interferometer system for linear distance and velocity measurements. The information contained in this chapter covers an overview of the optics to the process of aligning the system.

CHAPTER 6: PLANE/FLAT MIRROR MEASUREMENTS

This chapter contains information on how to setup and use optics for plane/flat mirror measurements where movement perpendicular to the laser axis is limited in traditional linear measurement optics. It steps the user through choosing a layout and mounting surface and the process of aligning the system.

CHAPTER 7: SYSTEM MAINTENANCE

This chapter explains the proper procedures for storing, cleaning and calibrating the components of the LZR2000 system.

CHAPTER 8: TECHNICAL DETAILS

This chapter supplies a variety of technical specifications for the LZR2000 system. General specifications, dimensions, signals and pinouts (as appropriate) are included for the laser head, the optics, and cables.

CHAPTER 9: TROUBLESHOOTING

This chapter provides a reference tool if problems arise with the LZR2000.

APPENDIX A: GLOSSARY

Appendix A contains a list of terminology and abbreviations used in this manual.

APPENDIX B: WARRANTY AND FIELD SERVICE

Appendix B contains the warranty and field service policy for Aerotech products.

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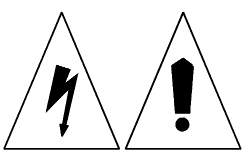
Throughout this manual the following conventions are used:



DANGER WARNING

- Danger and/or Warning symbols (see left) appear in the outer margins next to important precautions. Failure to observe these precautions could result in serious injury and/or damage to the equipment.
- The terms UNIDEX 500 and U500, UNIDEX 600 and U600 are used interchangeably throughout this manual.
- Keys such as Shift, Ctrl, Alt and Enter are enclosed in brackets (e.g., <Shift>, <Ctrl>, <Alt> and <Enter>) to distinguish them from individual keystrokes.
- Hexadecimal numbers are listed using a preceding "0x" (for example, 0x300, 0x12F, 0x01EA, etc.) to distinguish them from decimal numbers.
- The terms <Enter> and <Return> are used interchangeably throughout this document when referring to the keyboard.
- The terms retroreflector and retro are used interchangeably throughout this document.
- Graphic icons or keywords may appear in outer margins to provide visual references of key features, components, operations or notes.
- This manual uses the symbol "∇ ∇ ∇" to indicate the end of a chapter.

Although every effort has been made to ensure consistency, subtle differences may exist between the illustrations in this manual and the components that they represent.

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CHAPTER 1: INTRODUCTION

In This Section:

1.1. Overview of the LZR2000 Laser Feedback System

This chapter provides an introduction to the LZR2000 - a Laser Feedback System used for precision measurement applications such as machine tools, semiconductor lithography, optics fabrication, IC and LCD inspection, precision machining and others. The LZR2000 system is used to provide highly accurate position data in closed-loop motion control systems. Refer to Figure 1-1.

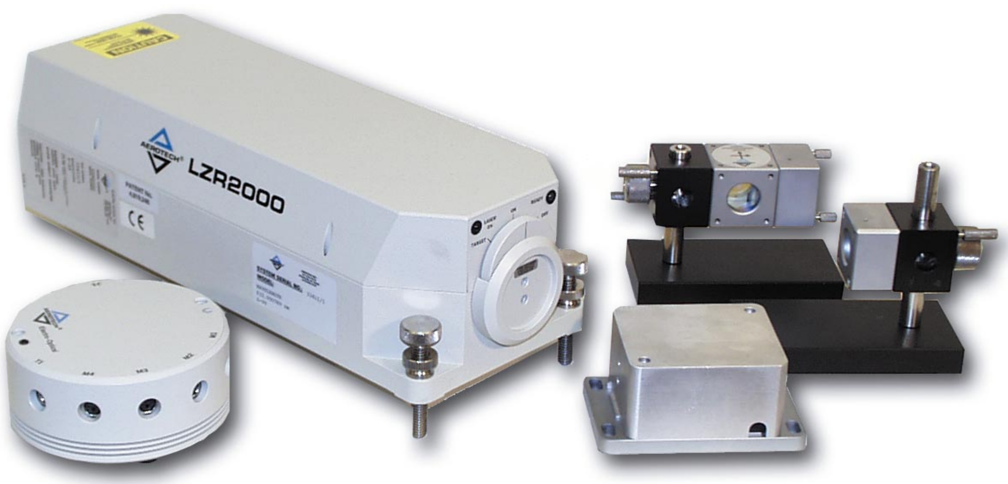


Figure 1-1. The LZR2000 System with Optional Environmental Compensator

1.1.1. General Description

The basic LZR2000 system is a highly accurate Laser Feedback System that consists of the following components:

- a single-frequency, helium-neon laser head
- one linear reflector
- one linear interferometer (polarized beam splitter and retroreflector combination)
- two alignment targets
- cables.

The laser head can also be purchased separately to complement existing optical components/systems or additional optical accessory kits can be purchased separately to complement other measurement requirements. Refer to Aerotech's *Motion Product Guide* for more information. A sample single-axis system is illustrated in Figure 1-2.

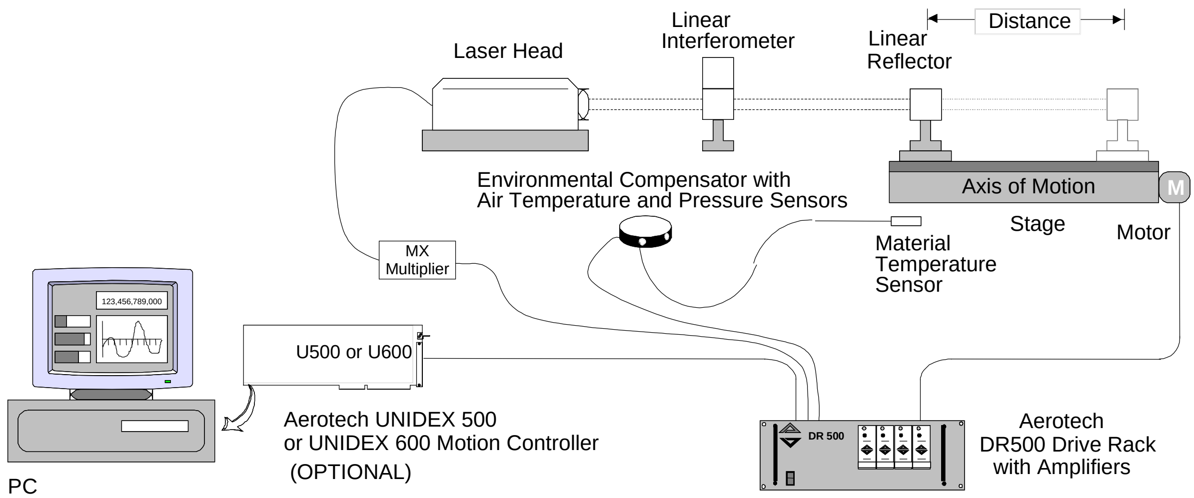


Figure 1-2. Sample Single-axis LZR2000 Configuration

This system provides resolution to 0.6 nm (0.024 μin) for enhanced positioning performance, as well as velocities up to 500 mm/sec at sub-micron resolution for increased productivity. Environmental compensation provides 0.15 μm/100 mm (6.0 μin/4.0 in) accuracy.

1.1.2. The LZR2000 Laser Head

The laser head of the LZR2000 system (shown in Figure 1-2 as part of a typical configuration) is the component responsible for generating the single-frequency laser beam and detecting/interpreting the interference patterns of the return beam. The head contains the circuitry needed to convert the interference patterns into standard A-quad-B line drive and A-quad-B sinusoidal (SIN/COS) signals. Laser head features include a single-frequency, helium-neon laser, internal DC power supply circuitry for the laser (converted from the external 100-240 volt AC switching power supply) and detector optics enclosed in a sturdy metal housing. External features include diagnostic LEDs (Laser On, Laser Ready), the laser beam exit and return apertures, a laser output control shutter (with Target, On and Off settings), output signal connectors and an AC power connector. A front view of the laser head is illustrated in Figure 1-3.

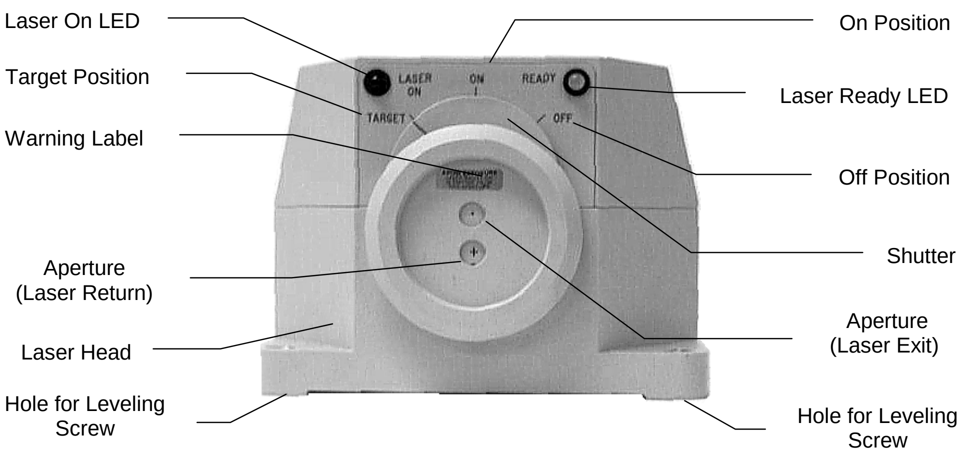
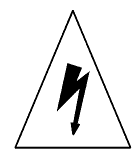
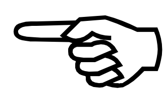


Figure 1-3. Front View of the Laser Head (LZR2000)

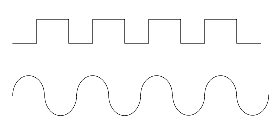


The laser head of the LZR2000 system emits laser radiation from the top aperture. Never stare directly into the laser beam or its reflections.

The “Laser On” LED (shown in Figure 1-3) is a red LED that is lit when power is supplied to the laser head. The “Laser Ready” LED is a green LED that is lit when the laser frequency has been stabilized (usually about 15 minutes after power is supplied to the laser head). Never attempt to use the laser head if the “Laser Ready” LED is not lit, otherwise inaccurate readings may result.



The “Laser on” LED will flash on and off during the 15 minute warm up of the laser head.



The laser head provides a standard λ/2 (316 nm) output signal in A-quad-B differential line driver and SIN/COS (analog) formats. The A-quad-B line driver output can interface directly to a motion controller that supports such inputs (e.g., an Aerotech UNIDEX 500, UNIDEX 600, etc.). However, the typical user will utilize the SIN/COS (analog) outputs connected to an Aerotech MXH multiplier box. The multiplier box multiplies the resolution and converts the signal to the standard differential (square wave) signal. Refer to Figure 1-2 on page 1-2. A rear view of the standard LZR2000 laser head shows the three connectors (for AC power connector, differential analog output signals and differential TTL output signals). A rear view of the LZR2000 laser head is shown in Figure 1-4.

The laser head of the LZR2000 contains no user-serviceable components and should not be opened.

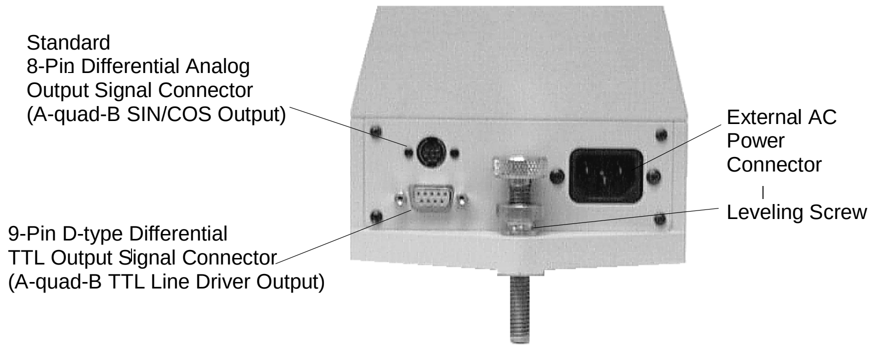


Figure 1-4. Rear View of the Standard LZR2000 Laser Head

An operation diagram of the laser head and optics is illustrated in Figure 1-5.

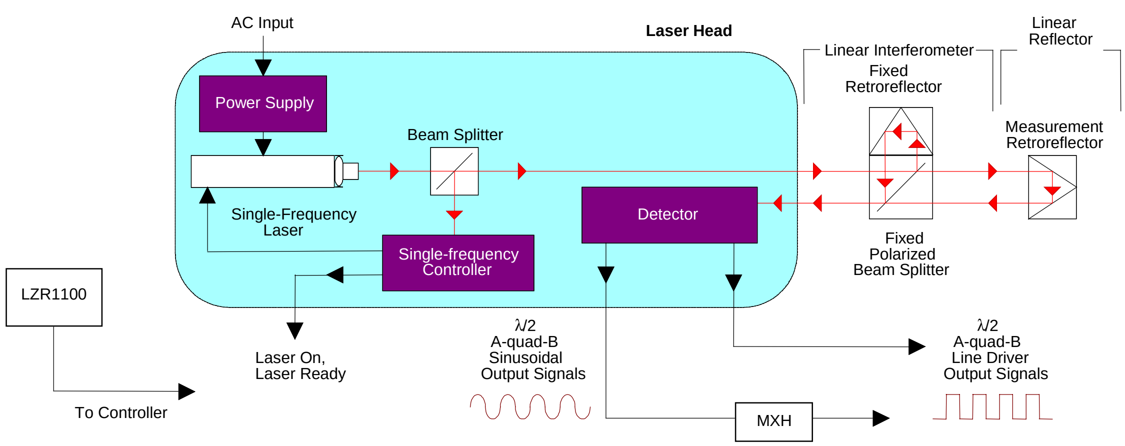


Figure 1-5. Operation Diagram of the Laser Head and Optics

1.1.3. Cables

The standard LZR2000 system includes a 6-foot AC power cord for the laser head. Other cables may need to be customized depending on the requirements and configuration of the system.

1.1.4. The Optics Package

The LZR2000 system includes an optics package needed for linear measurements. This standard optics package includes two retroreflectors and a single polarized beam splitter (PBS).

For interferometer configurations, the PBS is connected to one of the retroreflectors (retro). The linear interferometer (PBS/retro combination [LZR2300]) is either mounted along an axis that is parallel to the laser beam or perpendicular to it. The linear interferometer is positioned between the laser head and the second retroreflector (LZR2400). With the laser head and the linear interferometer mounted in fixed positions, the second retroreflector is mounted to a moveable base to form a path for the measurement beam. The PBS and the retroreflector of the linear interferometer form the path for the fixed reference beam. Figure 1-6 shows a complete LZR2000 system highlighting the roles of the linear interferometer and retroreflector optics. It is also possible to mount the linear reflector to a fixed surface and then mount the linear interferometer to the moveable surface. The laser head should never be the moveable component of the system.

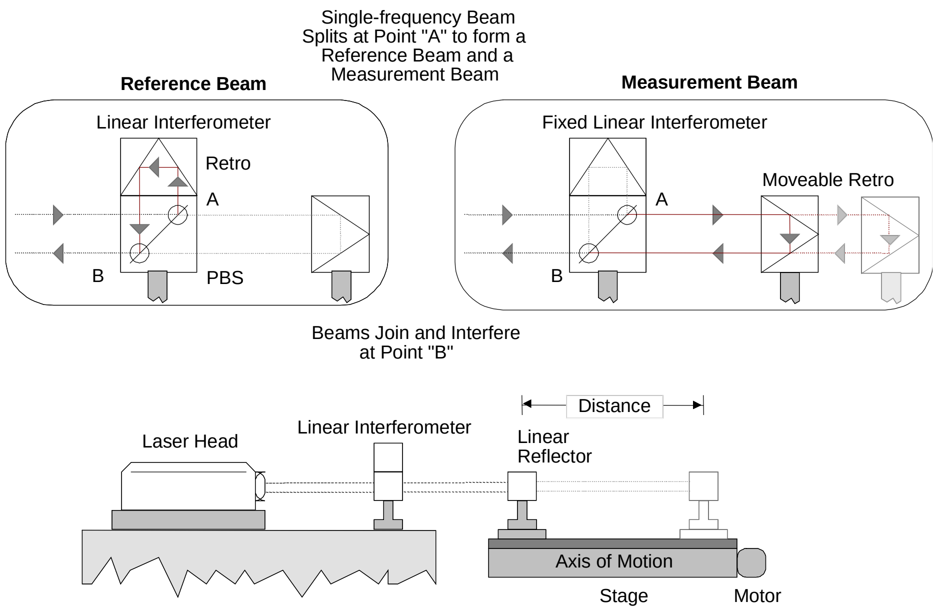


Figure 1-6. LZR2000 System Showing the Role of Optics

> The linear interferometer and the linear reflector should be positioned as close as possible to one another. This minimizes the effects of dead path error. Refer to Chapter 5: Linear Displacement and Velocity Measurements.

1.2. Theory of Operation

The LZR2000 interferometer uses laser and optical techniques to perform very accurate distance measurements. Linear, incremental displacement is determined using the relative shift in the laser beam's frequency between measurement and reference beams. This shift in frequency is introduced by the motion of either the measurement or reference object with respect to the other from a known starting (zero) point along the axis of motion. Refer to Figure 1-6. As a result of this motion (from some starting reference point to the destination point), an interference fringe is generated. This interference fringe is a dark and bright pattern that is detected and measured by the detector optics and circuitry in the laser head itself. The intensity of the interference fringe that is seen by the detector is a sinusoidal signal where the signal peaks correspond to bright lines of the interference fringe, and the valleys correspond to the dark lines.

1.3. Options and Accessories

A variety of options and accessories may be purchased with the LZR2000 system to enhance its standard operation. Refer to Table 1-1 for part numbers and descriptions.

Table 1-1. Options and Accessories Available for the LZR2000 System

Part #	Description
LZR2250	Angular/Linear Combination Optical Kit
LZR2700	Plane Mirror Optical Kit
LZR2900	Linear Optical Kit
LZR1001	Post-mounted height adjusters
LZR1002	Base Plate
LZR1003	90 degree turning mirror cube
LZR1004	Mirror (0 degree incidence)
LZR1005	Mirror (45 degree incidence)
LZR1010	Material temperature sensor with cable (requires LZR1100)
LZR1020	Remote Ambient Temperature Sensor
LZR1100	Environmental compensation electronics, air and pressure sensor, and 10-foot cable
AR-4	4 in (100 mm) length post with standard threads
AR-4M	4 in (100 mm) length post with metric threads
AR-6	6 in (150 mm) length post with standard threads
AR-6M	6 in (150 mm) length post with metric threads
LZR-TRIPOD	Heavy duty tripod with precision 3-axis alignment head/mounting plate
CASE1	Storage/Travel case for laser head and optics
CASE2	Storage/travel case for tripod

1.4. Applications and Configurations

The laser interferometer is an accurate and versatile scientific tool. The standard LZR2000 system contains the laser and optical components necessary to perform linear measurement.

> The sample configurations provided in the following sections are configurable with any motion control system (e.g., UNIDEX 500, UNIDEX 600, etc.) and not just specifically for the system illustrated in the examples.

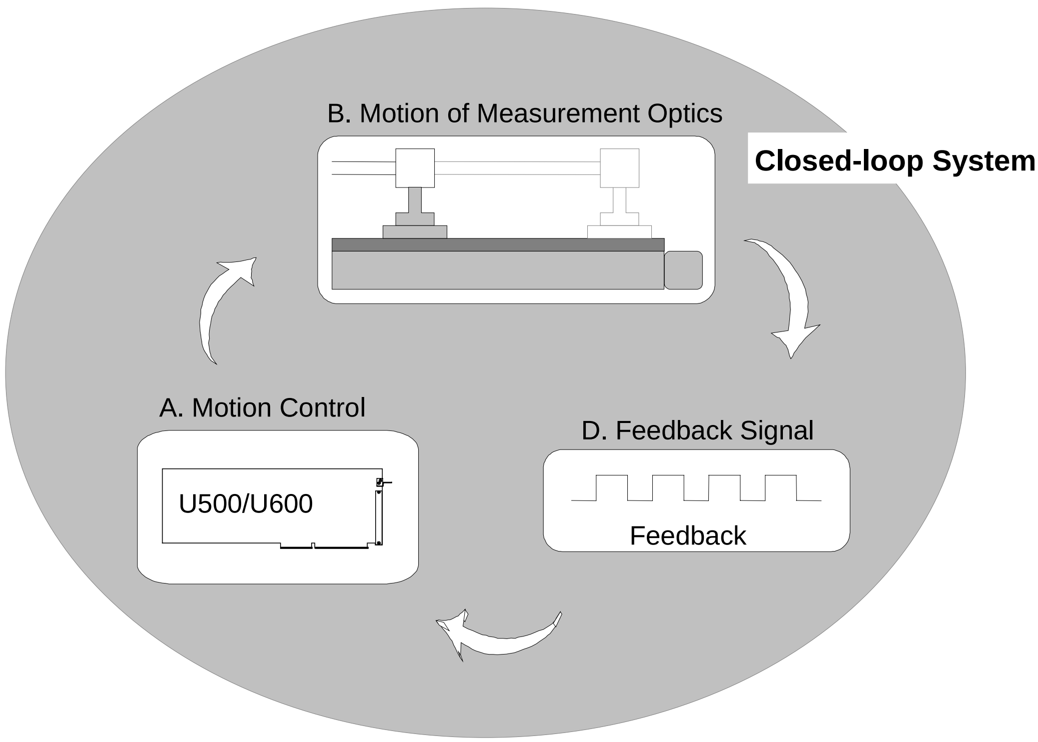


Figure 1-7. Closed-loop Systems

1.4.1. Sample Configuration 1: Motor Control Based on Interferometer Position Feedback Using a Signal Multiplier and an External Motion Controller

This sample configuration is similar to the other examples, only a signal multiplier is used. The A-quad-B sinusoidal signal from the laser head (9 pin D-type connector) is sent to the signal multiplier using a customized cable. (Refer to Chapter 8: Technical Details for laser head pinouts. Refer to documentation supplied with the MXH signal multiplier for input/output pinouts and technical information). The output of the signal multiplier is sent to the motion controller.

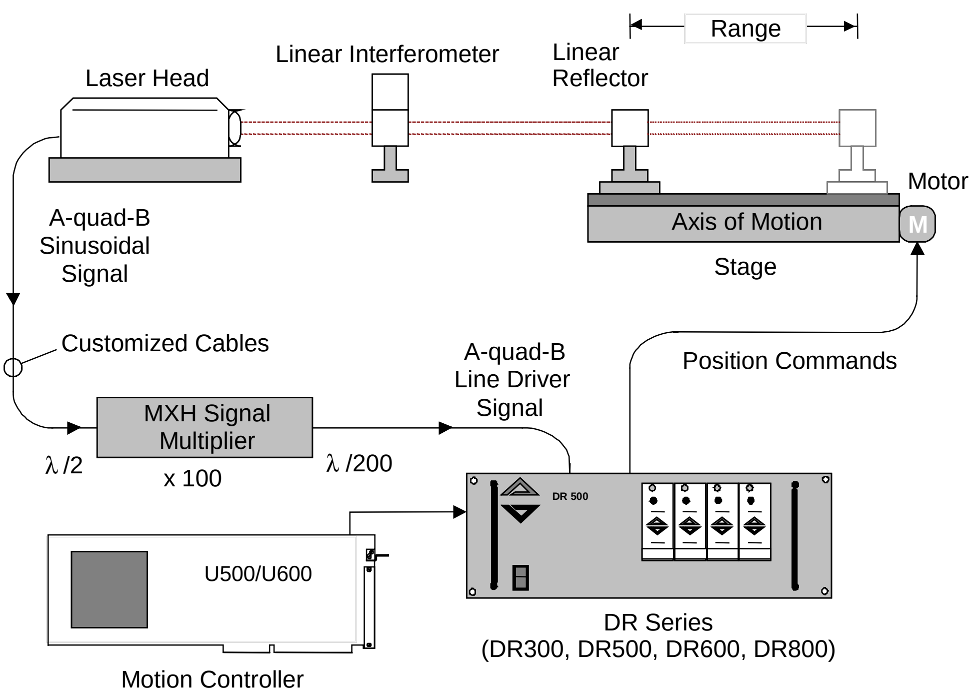


Figure 1-8. Closed-loop Position Feedback Application Using a Multiplier

Consider a motion controller (e.g., a UNIDEX 500, UNIDEX 600, etc.) that requires very accurate positioning. In this application, a motion controller commands the axis to a desired position while the laser interferometer provides the highly accurate position feedback. The A-quad-B sinusoidal position signal (with a resolution of λ/2) is sent from the laser head to the MXH multiplier. The signal multiplier then provides an A-quad-B line driver signal output (with a λ/200 resolution, for example). This multiplied signal is sent back to the motion controller. A signal multiplier configuration is illustrated in Figure 1-8.

1.4.2. Sample Configuration 2: Temperature, Pressure and Humidity Compensation for Enhanced Accuracy

Measurement accuracy is dependent on the wavelength of light. The wavelength of light, in turn, is affected by air temperature, pressure, and humidity. The optional environmental compensator (LZR1100) and remote material temperature sensor (LZR1010) packages measure any temperature and pressure changes and compensates the wavelength to provide a system accuracy of 0.15 µm per 100 mm.

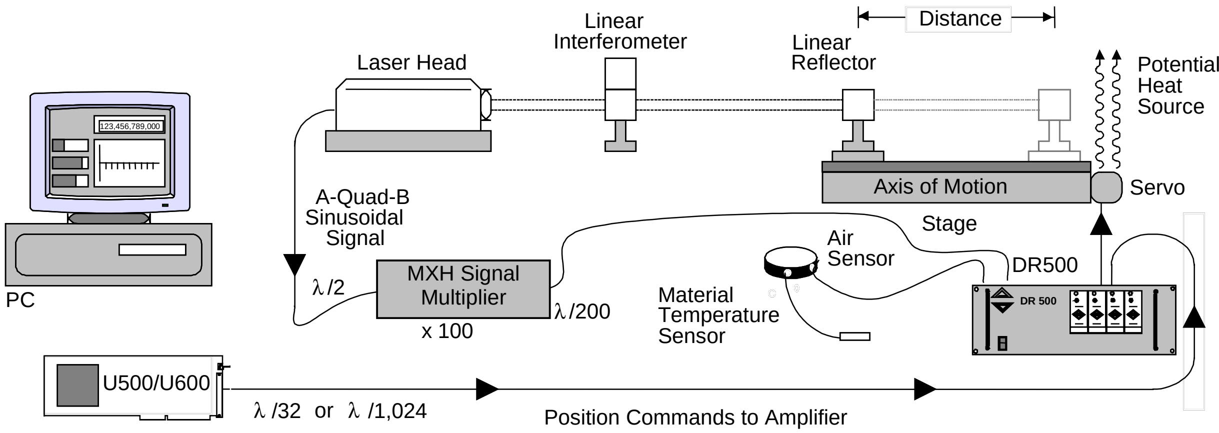


Figure 1-9. Sample Environmental Compensation Configuration

A sample configuration showing the use of the temperature and pressure compensation option is illustrated in Figure 1-9. Humidity compensation is entered manually.

> To help minimize the effects of ambient temperature fluctuations, always plan the system layout so that potential heat sources (e.g., stage motors, air conditioning/ heating ducts, etc.) do not directly radiate into the path of the laser beam.

> See the controllers online help file documentation for more information on using the LZR1100.

1.4.3. Sample Configuration 3: Motor Control Using an External Motion Controller with Interferometer Position Feedback

This sample configuration illustrates an application that uses a generic motion controller for positioning and an LZR2000 laser head (with optics) for highly accurate position feedback information. This configuration requires an LZR2000 laser head, optics, cables and a motion controller.

In this example, an LZR2000 laser head is connected to the motion controller using a customized cable. Precise position information in the form of A-quad-B line driver signals is sent from the laser head to the motion controller. A linear stage with a motor defines the axis of motion on which the measurement reflector is mounted.

After the motion controller commands the stage to move, position feedback signals from the laser head are sent back to the motion controller. Figure 1-10 illustrates a sample closed-loop motion control configuration that uses interferometer position feedback from the laser head.

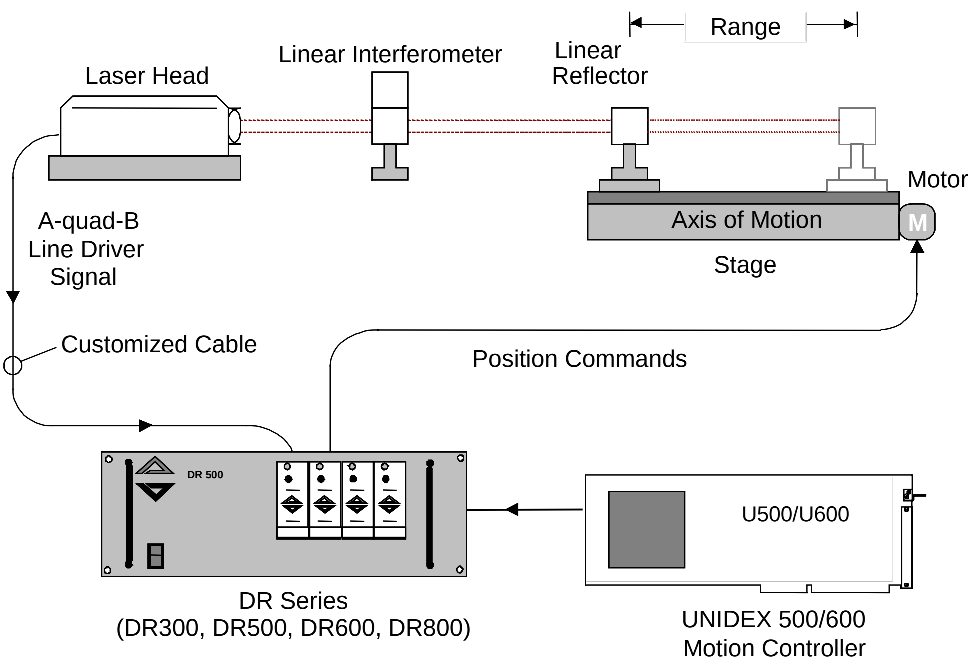
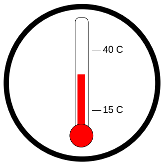
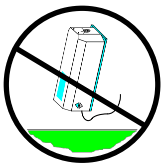


Figure 1-10. Sample Motion Control Configuration with Interferometer Feedback

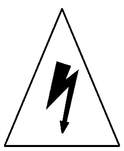
1.5. Proper Handling and Storage Techniques



The LZR2000 system contains precision measurement equipment. All components should be handled carefully to ensure proper operation. Exposure to harsh elements such as excessive temperatures (exceeding 15-40° C), humidity extremes (above 90%, non-condensing), and shocks/vibrations (in excess of 30 g for 11 ms) should be avoided. When not used for extended periods of time, the LZR2000 system components should be stored in their original packaging. Electronic hardware and optics should be kept where they are not subject to physical abuse, excessive dirt, temperature, moisture, or vibration.

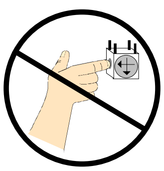


Although the laser head of the LZR2000 system consists of a rugged metal enclosure, it houses sensitive components such as a laser and precision optics. Never drop or bump the laser head. In addition, the laser head contains no user-serviceable parts and should not be opened. Opening the laser head can cause serious electrical injuries and will void the warranty.

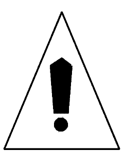


DANGER

Never remove the protective cover from the laser head. There are no user-serviceable components inside. Removal may cause severe electrical shock, irreparable component damage, excessive radio frequency (RF) interference, and will void the Aerotech warranty.



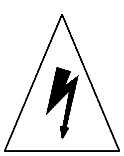
Like the laser head, the optics used in the LZR2000 system are precision devices that should be handled carefully. Never touch the glass or mirrored surfaces of any optical device in the LZR2000 system (i.e., the linear reflector and the linear interferometer). Touching these surfaces can leave residue that may interfere with the accuracy of the system.



WARNING

Never touch the glass or mirrored surfaces of the optical components in the LZR2000 system.

LZR2000 system cables should be installed so that they do not interfere with the operation of the system. Never kink or severely bend any cable in the LZR2000 system. Never disconnect a cable by pulling on the cable. Instead, hold the cable by its connector and gently remove it. Never connect or disconnect cables to a system that already has power supplied to it.

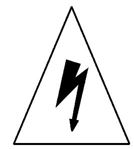


DANGER

Be sure that system power (i.e., power to the PC, the optional motion controller, etc.) is turned off before connecting or disconnecting any system cables.

1.6. Laser Safety and Precautions

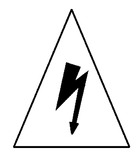
This product is a Class II laser product conforming to the Federal Bureau of radiological health regulations 21 CFR 1040.10 and 1040.11 and to the laser international laser safety regulations. The output beam of the LZR2000 laser head is limited to less than 1.0 mW output power with a maximum intensity of 0.1 mW/mm^2. At these low power levels, eye protection is not required for normal scatter or indirect reflections. However, no one should ever look directly into the beam of the laser. The pulse specification is continuous wave, the laser medium is helium-neon, and the wavelength is 632.9907 nanometers.



DANGER

> Never look directly into the beam of the LZR2000 laser head.

The laser head has appropriate grounding connections for the HeNe laser. Under no circumstances should the ground be defeated or circumvented.



DANGER

> Never attempt to defeat or circumvent the ground connection on the LZR2000.

The input voltage to the laser head can exceed 10,000 volts during startup. Even though the available output current is limited to a relatively safe limit, exercise extreme caution when using the LZR2000 system.

Two labels (a caution label and a shipping label) are attached to the standard laser head to warn operators of potential hazards. These labels are illustrated in Figure 1-11.

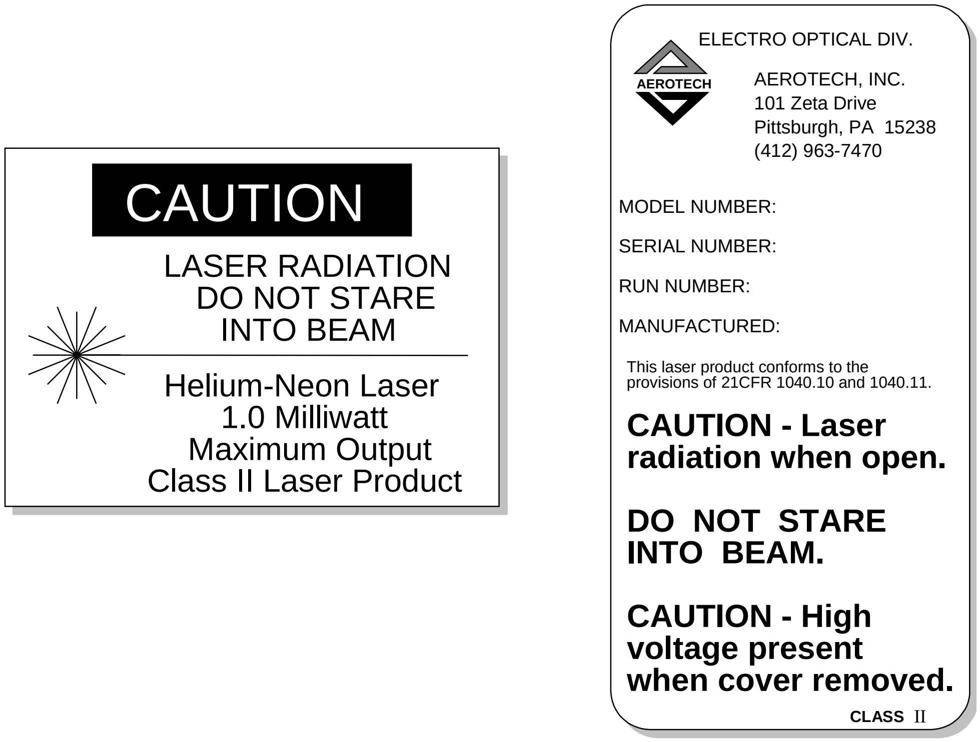


Figure 1-11. Standard Caution and Shipping Labels

DANGER

Use of controls, adjustments, or performance of procedures, other than those specified herein, may result in hazardous radiation exposure.

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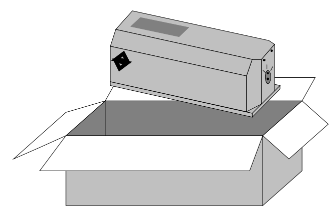
CHAPTER 2: UNPACKING AND INSPECTING THE LZR2000 SYSTEM

In This Section:

2.1. Introduction

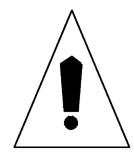
Chapter 2 sets the groundwork for the actual installation and setup of the individual system components. This chapter steps the operator through the logical sequence of unpacking the LZR2000 system components and then inspecting them for damage or looseness that may have occurred during shipment.



2.2. Unpacking the Components

Before unpacking any components, visually inspect the containers of the LZR2000 system for any evidence of shipping damage. If any such damage exists, notify the shipping carrier immediately.

All electronic equipment is wrapped in antistatic material and packaged with desiccant (a drying agent used to reduce moisture). Make certain that the antistatic material is not damaged during unpacking.

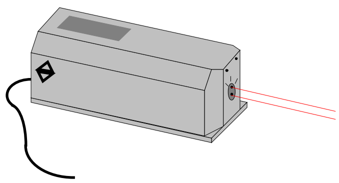


WARNING

Remove the packing list from the LZR2000 container(s). Make sure that the items specified on the packing list are contained within the package(s). The items listed in Table 2-1 may be included with the LZR2000 system. Visually inspect all items that are received. Key details in the inspection process are listed in the sections that follow.

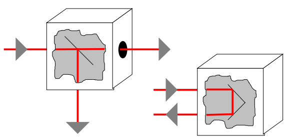
Table 2-1. Minimal System Components

Part #	Description
LZR2000	1 Single-frequency HeNe Laser Head
LZR2300	1 LZR2300 Linear Interferometer
LZR2410	2 LZR2410 Alignment Targets
--	1 Signal Cable
EDU169	1 Operations and Technical Manual.



2.3. Inspecting the LZR2000 Laser Head

All products undergo a total quality inspection before they are shipped from Aerotech. Even with a stringent quality assurance program, however, it is still possible that a product may arrive in less than perfect condition due to improper handling during shipment. After unpacking the LZR2000 laser head, check to ensure that the laser head has no visible signs of damage. Also, ensure that the shutter rotates without excessive resistance into its three positions (Off, On, and Target).



2.4. Inspecting the Optical Packages

After unpacking the optics package, inspect the components for visible signs of damage or breakage. Be careful not to touch any glass or reflective surfaces of the optical devices. Contact with these surfaces can leave oil and dirt residue from the fingerprints. This residue can be detrimental to the proper operation of the optical components of the Laser Feedback System. The linear reflector and interferometer are illustrated in Figure 2-1.

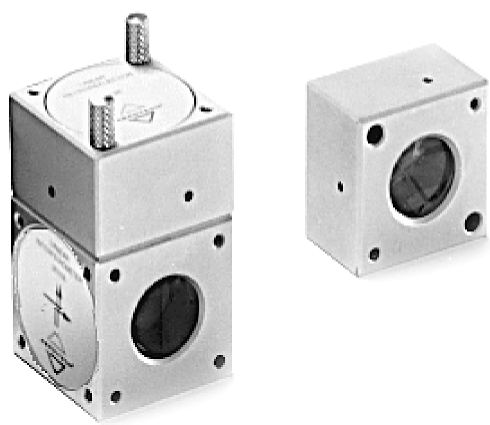
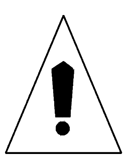


Figure 2-1. The Linear Interferometer and Reflector Optics



WARNING

Never touch the glass and reflective surfaces of the optical components. Residue from fingerprints can interfere with the proper operation of the Laser Feedback System.

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CHAPTER 3: GETTING STARTED, A FIRST LOOK

In This Section:

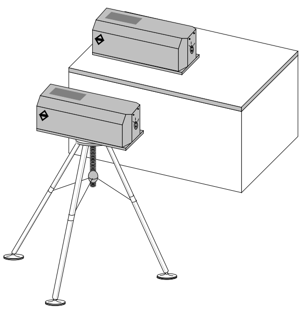
3.1. Introduction

The information in this chapter provides the user with a first look at the LZR2000 Laser Feedback System. This chapter is designed to briefly walk the user through setting up the laser head and connecting the signal cables.

IMPORTANT

Individuals that need detailed explanations about other features, techniques, and procedures should review Chapter 4 through Chapter 9.

Also, the information in this chapter is just one example to help the user become familiar with the LZR2000 Feedback System. It should not be regarded as the only configuration or use of the system.



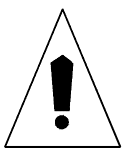
3.2. Physical Setup of the Laser Head

This section explains how to install and setup the laser head and tripod (if used) in the LZR2000 system. This includes choosing suitable locations for the laser head and positioning the laser head.

3.2.1. Mounting the Laser Head

Typically, the laser head can be mounted on either a tripod or directly to a flat, fixed (non-moving) rigid table.

Before beginning, decide on the desired/required position for the laser head.



IMPORTANT

The mounting surface for the LZR2000 System should be a fixed, vibration-free surface. Vibrations can cause erroneous readings and possible damage to the equipment.

For standard table mounting, the laser head is secured to the table (or optical breadboard) using the supplied leveling screws. For tripod configurations, the laser head is mounted to the tripod's mounting plate using three supplied leveling screws. Figure 3-1 illustrates tripod and stationary table mounting diagrams of the laser head.

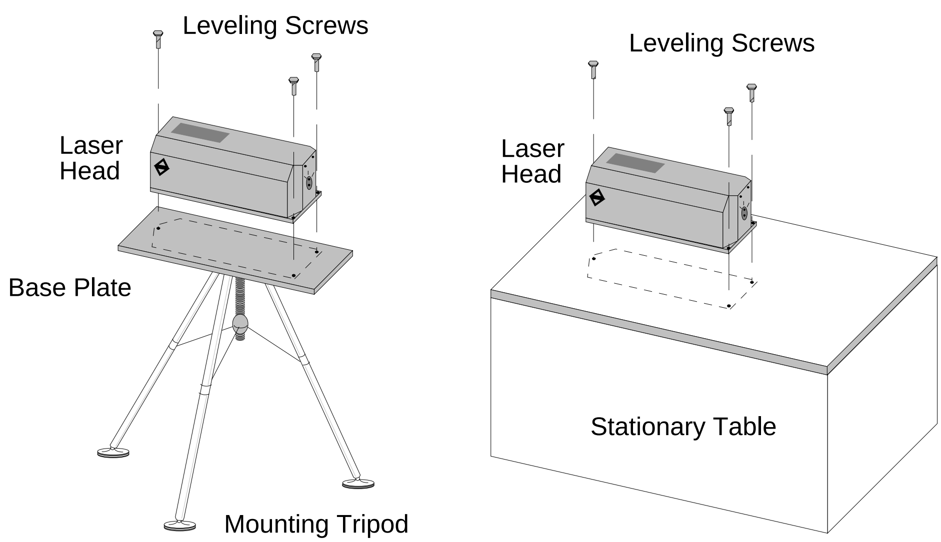


Figure 3-1. Mounting the Laser Head on a Tripod and on a Stationary Table

3.2.2. Setup of the Laser on the Tripod

If the desired installation of the laser head is with the tripod, decide on the required position for the laser head. Also, refer to Figure 3-2 and Figure 3-3 for setup of the tripod and use of the positioning controls. *For more detailed instructions, turn to Chapter 4: Physical Setup of the Laser Head.*

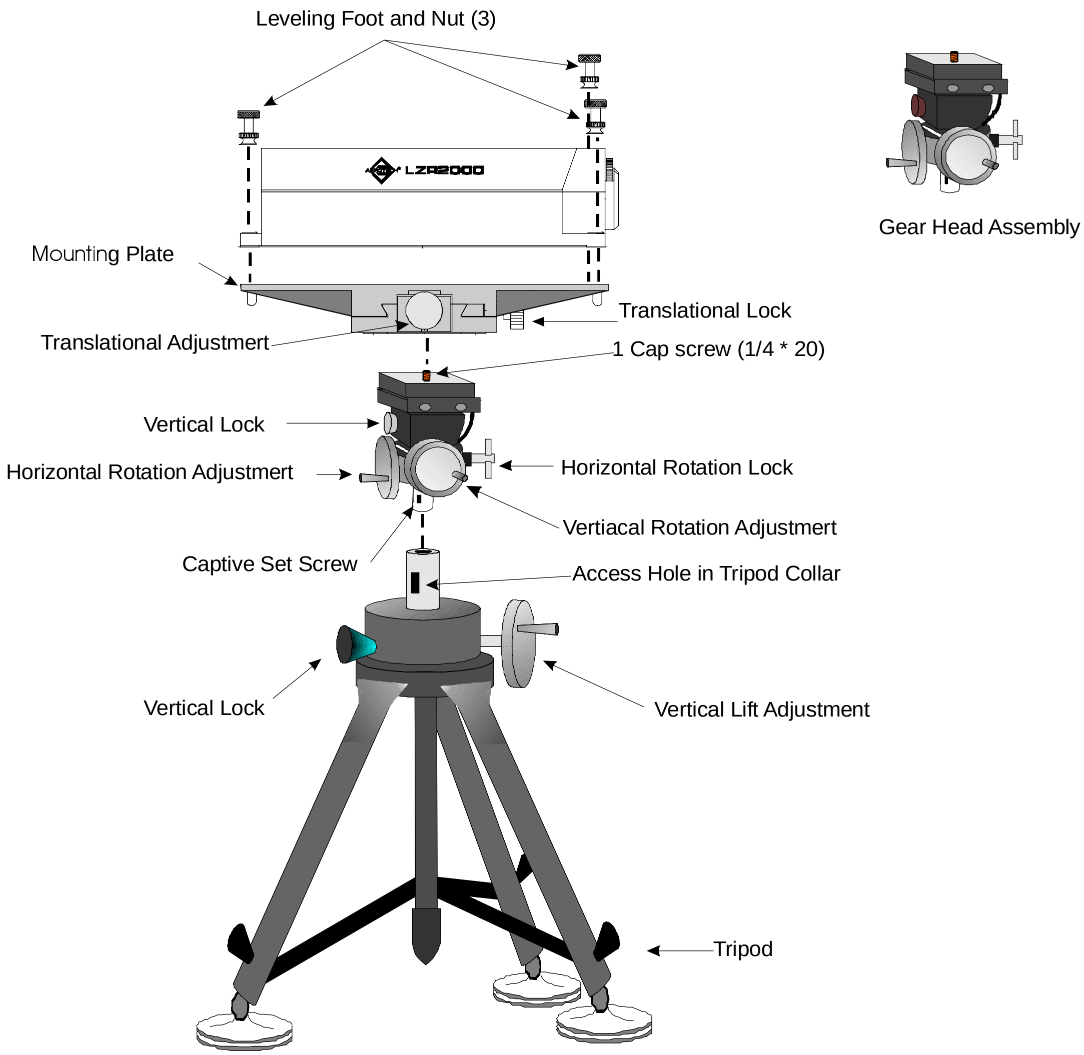


Figure 3-2. Setup of Tripod and Installation of the Laser Head

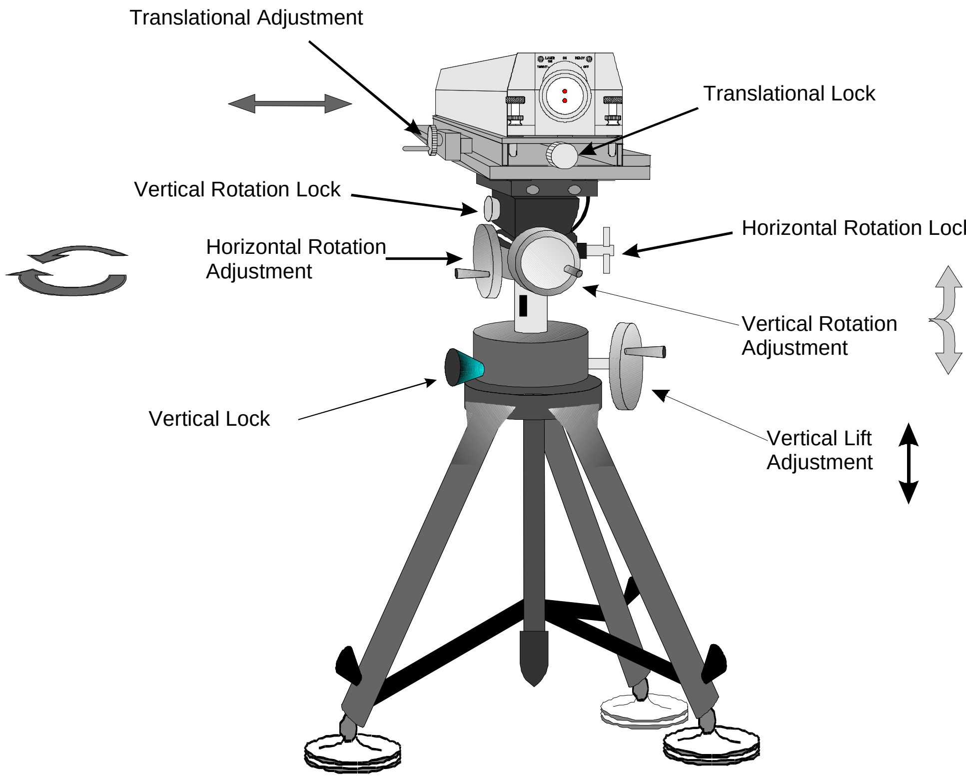


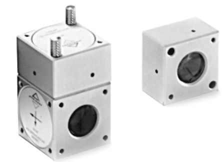
Figure 3-3. Laser Head Motions with Position Controls

3.2.3. Leveling the Laser Head

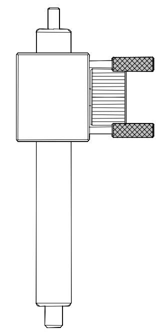
Positioning one leg of the tripod in line with the laser beam in most cases will make it easier to level the baseplate.

Observing the bubble level on top of the tripod, adjust the leg lengths until the baseplate is level. This is done by loosing the black knobs on each leg of the tripod. Ensure the knobs are securely tightened when the leveling operation is complete.

3.3. Optical Components and Alignment Aides



The optics portion of the LZR2000 System consists of a linear reflector (LZR2400) and a linear interferometer (LZR2300). These optical components are used in linear displacement and velocity measurement applications.



Mounting hardware is also available for the reflector and linear interferometer that allows attachment to most machine surfaces and tool spindles. Post-mount height adjusters connect to the optical devices using a pair of knurled screws, refer to Figure 3-4. Then the height adjusters attach to a variety of optical posts available with threaded ends in either standard or metric threads. Figure 3-5 provides examples of alternative ways to mount the retroreflector.

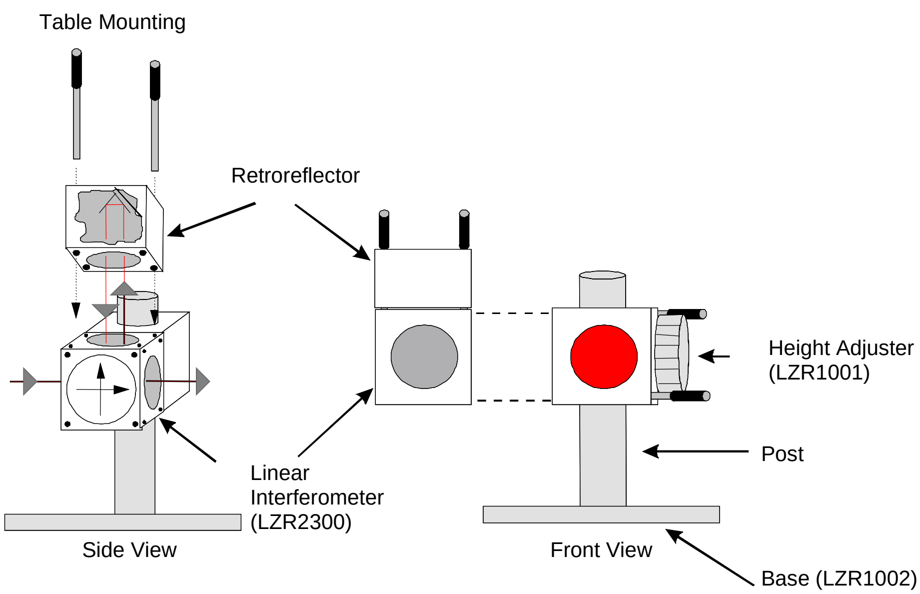


Figure 3-4. Interferometer Mounting

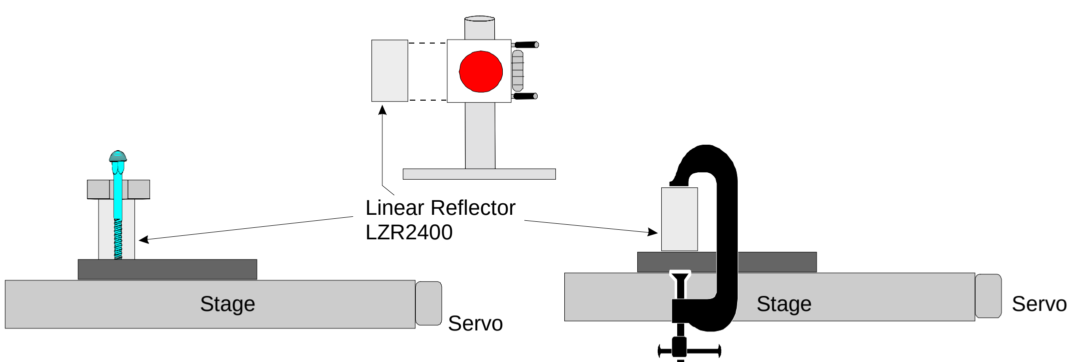


Figure 3-5. Alternate Methods of Mounting the Reflector

3.4. Layouts and Configurations

There are several optical configurations that are available for linear measurement applications. We will use a configuration that best suits the particular application. The interferometer is always placed in between the laser head and two retroreflectors, refer to Figure 3-6. Normally, one of the retroreflectors will be physically attached to the interferometer and the other will be allowed to move with respect to the interferometer.

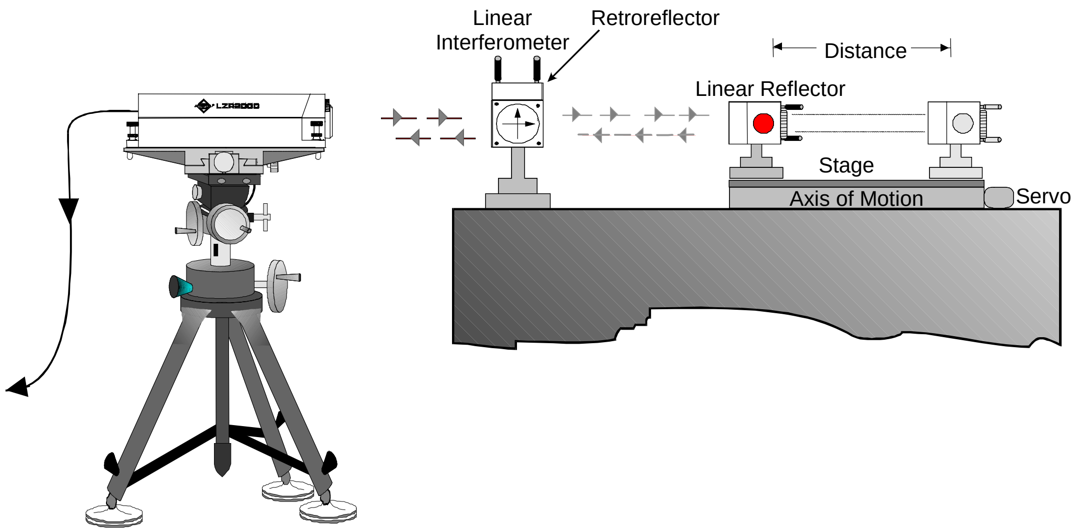
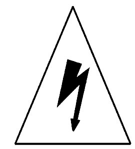


Figure 3-6. Laser Head, Interferometer, and Reflector Setup

3.5. Aligning the System

The alignment of optical components in the system is performed visually using the laser beam from the laser head.



> The laser head of the LZR2000 System emits laser radiation from the top aperture. Never stare directly into the laser beam or its reflection.

It is recommended that the “Ready” LED be illuminated before beginning the alignment process. The “Ready” LED indicates that the laser has been stabilized and is ready for taking measurements. It takes approximately 15 minutes for the “Ready” LED to come on after power is supplied to the laser head.

The following outlines the process of getting acquainted with coarsely aligning and setting up the system. *For more detailed alignment instructions, turn to Chapter 5: Linear Displacement and Velocity Measurements.*

1. Turn on the laser and allow it to stabilize while positioning the optics. Set the shutter to the target (+) position. Refer to Figure 3-7.

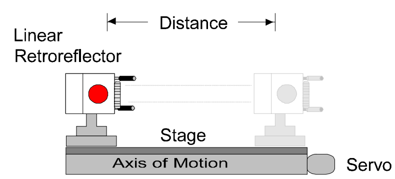
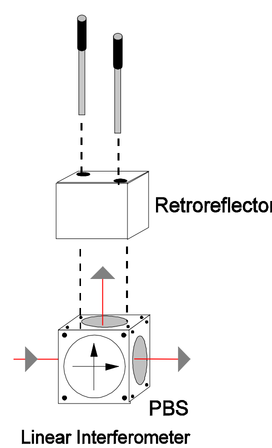


Figure 3-7. Front View of Laser Head

2. Mount the linear reflector (retroreflector) so that its opening is facing the exit aperture of the laser head. Be sure to orient the retroreflector and/or laser head so that the laser beam will hit the center of a “triangle” and be reflected to the opposite “triangle.” Refer to Figure 3-8.
3. Position the moveable table/stage so that the retroreflector is at the travel limit closest to the laser head.
4. When the laser is stabilized, adjust the laser head so that the return beam hits the center of the target on the laser head.
5. Now move the table/stage so that the retroreflector moves to the travel limit that is furthest from the laser head. During this movement, align the head so that the return beam is always centered on the target. Refer back to Figure 3-6.



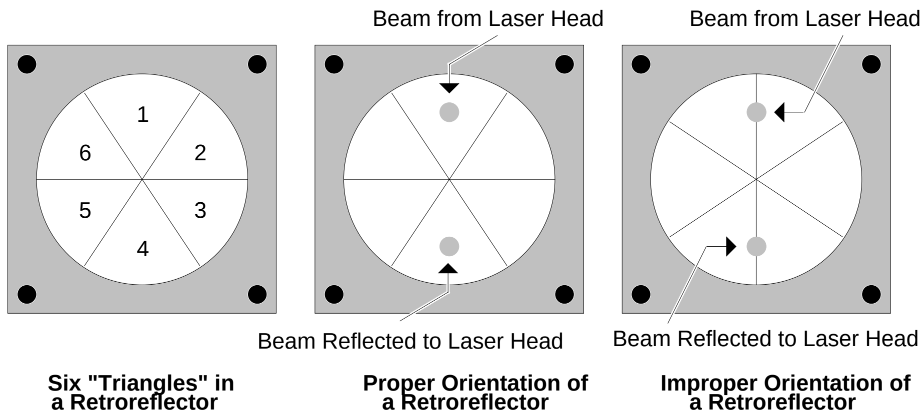
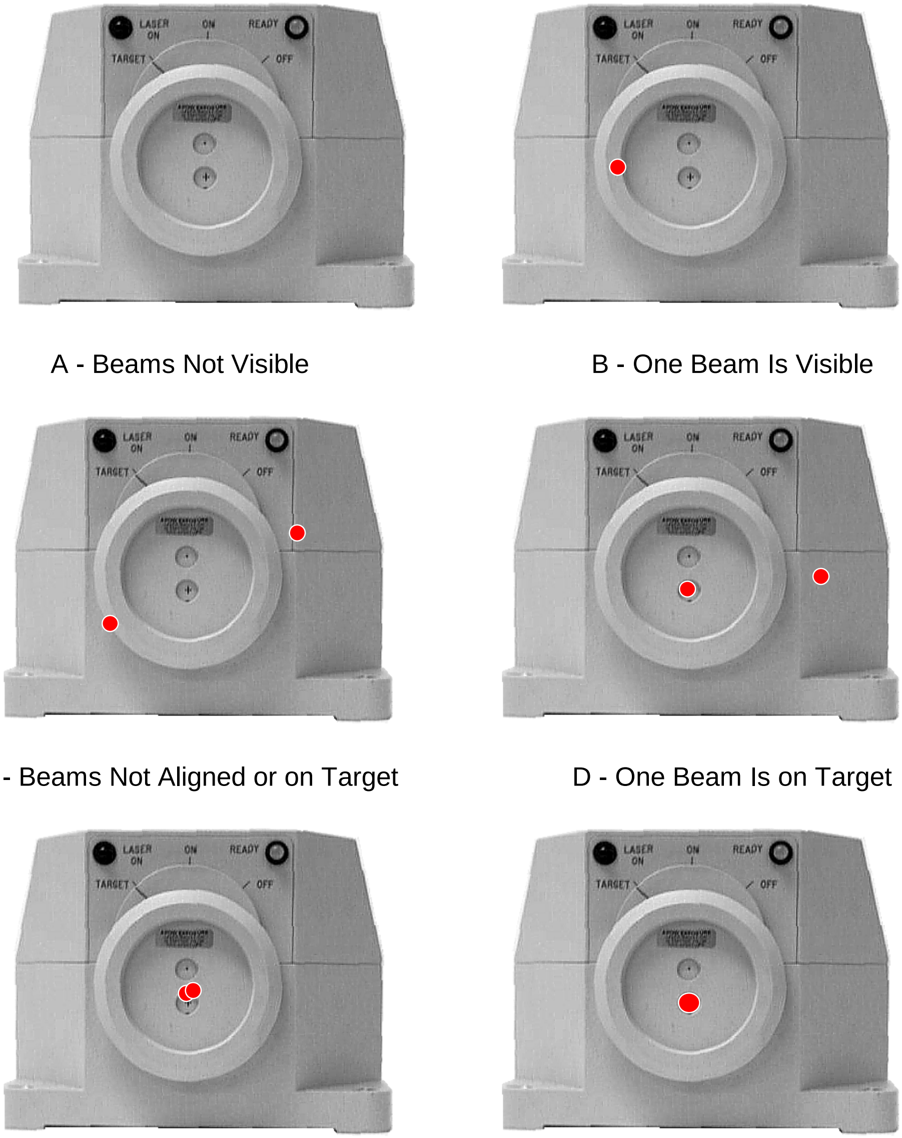


Figure 3-8. Front View of a Retroreflector

6. Mount and position the linear interferometer on a non-moving surface between the laser head and the measurement retroreflector so that the beam hits the upper half of the PBS opening. The retroreflector of the linear interferometer should be oriented so that the portion of the laser beam reflected by the PBS will (1) hit the center of a “triangle”, (2) be reflected to the opposite “triangle”, (3) return to the PBS, and (4) be reflected back to the laser head. Refer to Figure 3-8.
7. The linear interferometer should be mounted as closely as possible to the measurement reflector. This distance should be minimized so that the measurement beam is minimally effected by air temperature, pressure and humidity differences.
8. Verify that the measurement reflector does not interfere with the linear interferometer at any point in the travel range.
9. Block the transmitted beam between the interferometer and the reflector (using a piece of paper, for example) and adjust the linear interferometer assembly so that the reference portion of the return beam hits the center of the target on the laser head. Refer to Figure 3-9.
10. Remove the piece of paper and perform the same adjustment to the reflector until its return beam is also centered on the crosshair of the lower aperture on the laser head. Refer to Figure 3-9.
11. Repeat the previous steps to fine tune the system further.

There should be only one dot visible on the lower aperture, since both beams overlap each other completely. Refer to Figure 3-9.

12. Rotate the shutter of the laser head to the ON position.



A - Beams Not Visible

B - One Beam Is Visible

C - Beams Not Aligned or on Target

D - One Beam Is on Target

E - Both Beams Nearly Aligned

F - Beams Aligned and on Target

Figure 3-9. Different Degrees of Beam Alignment (View from Front of Laser Head)

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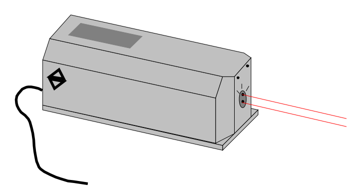
CHAPTER 4: PHYSICAL SETUP OF THE LASER HEAD AND TRIPOD

In This Section:

4.1. Introduction

This chapter explains how to install and setup the laser head and tripod used in the LZR2000 System. This includes choosing suitable locations for the laser head, supplying power and signal cables to the laser head, and positioning the laser head.

4.2. The LZR2000 Laser Head



The LZR2000 laser head (shown at right and in Figure 4-1) is the component responsible for generating the single-frequency laser beam and detecting/interpreting the interference patterns of the return beam. The head contains the circuitry needed to convert the interference patterns into standard A-quad-B line driver and A-quad-B sinusoidal (SIN/COS) signals. Laser head features include a single-frequency, helium-neon laser, internal DC power supply circuitry for the laser (converted from the external 100-240 volt AC switching power supply) and detector optics enclosed in a sturdy metal housing. External features include diagnostic LEDs (Laser On, Laser Ready), the laser beam exit and return apertures, a laser output control shutter (with Target, On and Off settings), output signal connectors and an AC power connector. A front view of the laser head is illustrated in Figure 4-1.

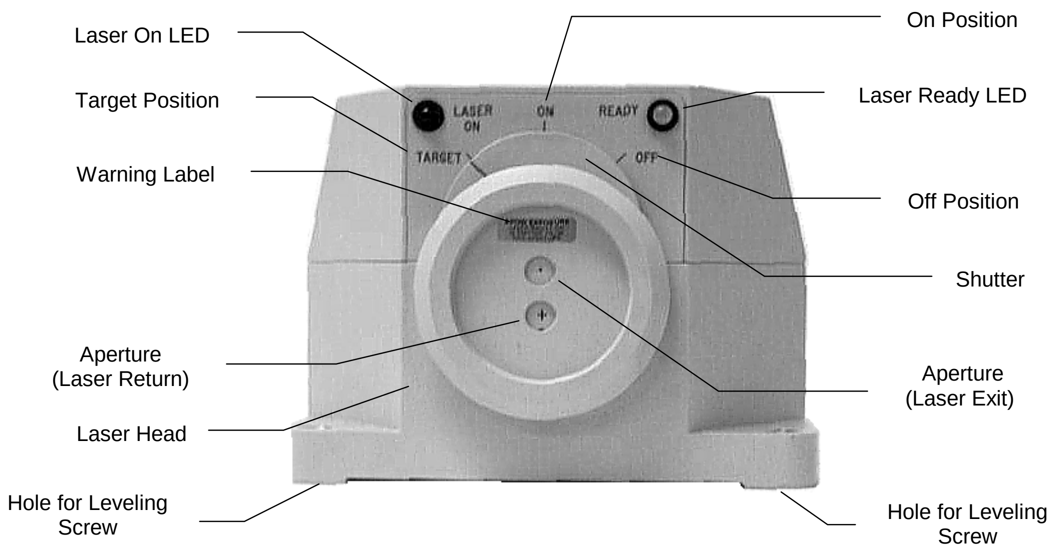


Figure 4-1. Front View of the Laser Head (LZR2000)

DANGER

> The laser head of the LZR2000 system emits laser radiation from the front top aperture. Never stare directly into the laser beam or its reflections.

The "Laser On" LED (shown in Figure 4-1) is a red LED that is lit when power is supplied to the laser head. The "Laser Ready" LED is a green LED that is lit when the laser frequency has been stabilized (usually about 15 minutes after power is supplied to the laser head). Never attempt to use the laser head if the "Laser Ready" LED is not lit, otherwise inaccurate readings may result.

> The "Laser on" LED will flash on and off during the 15 minute warm up of the laser head.

A rear view of the standard LZR2000 laser head shows the three connectors (for AC power connector, differential analog output signals and differential TTL output signals). A rear view of the LZR2000 laser head is shown in Figure 4-2.

> The laser head of the LZR2000 contains no user-serviceable components and should not be opened.

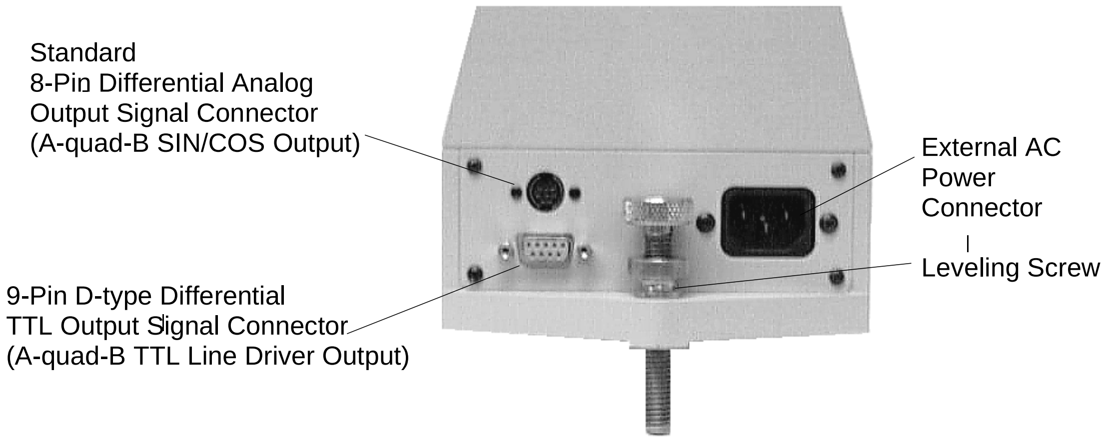
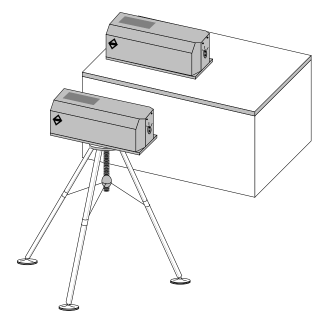


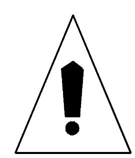
Figure 4-2. Rear View of the Standard LZR2000 Laser Head



4.3. Mounting the Laser Head

Typically, the laser head can be mounted on either a tripod or directly to a flat, fixed (non-moving) rigid table. The placement, orientation and alignment of the laser head, regardless of the method of mounting, depend on the desired configuration as well as other factors such as the size of the work area and the amount of clearance between system components. These factors may ultimately dictate how the laser head must be mounted and/or oriented.

The mounting surface for the LZR2000 System should be a fixed, vibration-free surface. Vibrations can cause erroneous readings and possible damage to the equipment.



For standard table mounting, the laser head is secured to the table (or optical breadboard) using the supplied leveling screws. For tripod configurations, the laser head is mounted to the tripod's mounting plate using three supplied leveling screws. Figure 4-3 illustrates tripod and stationary table mounting diagrams of the laser head.

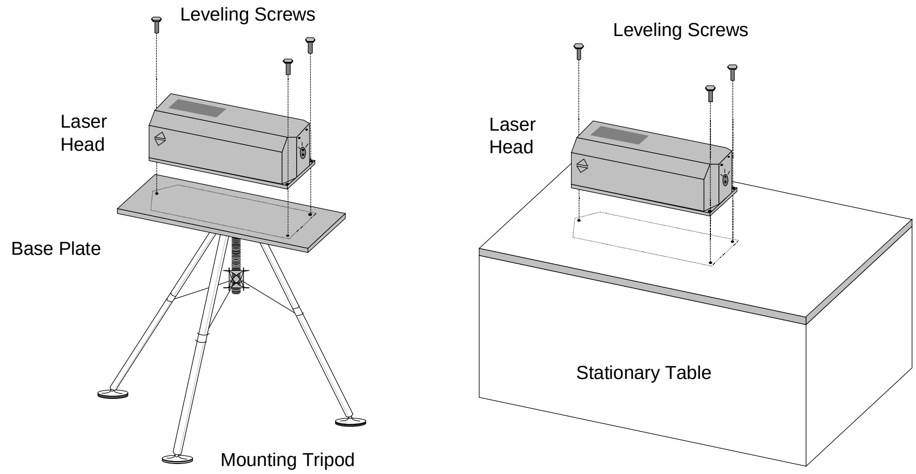


Figure 4-3. Mounting the Laser Head on a Tripod and on a Stationary Table

4.3.1. Setup of the Laser on the Tripod

If the desired installation of the laser head is with the tripod, decide on the required position for the laser head. Also, follow the steps listed next when setting up the tripod for installation of the laser head. Refer to Figure 4-4.

1. Insert the geared head assembly into the tripod collar.
    a) Ensure that the captive set screw is in place inside the geared head assembly and is not protruding out.
    b) Position the geared head assembly so the captive set screw lines up with the access hole in the tripod's collar.
    c) Using the supplied 3/17-inch Allen wrench, tighten the set screw in the geared head assembly. This prevents the geared head assembly from moving in relation to the tripod's collar.
    d) Adjust the height of the geared head by using the vertical lift adjustment on the tripod.
    e) Tighten the vertical lock on the tripod. This prevents the geared head from moving up or down from within the tripod.
    f) Lock the horizontal rotation lock on the geared head. This prevents the geared head from rotating left or right.
    g) Using the vertical rotation adjustment, adjust the geared head until it appears to be level.
    h) Lock the vertical lock on the geared head. This prevents the geared head from moving up or down.

2. Line up the mounting plate with the cap screw on the geared head and secure the mounting plate to the geared head by tightening the cap screw. The cap screw is accessible through an opening in the geared head. Ensure that the front of the base plate is positioned so that vertical rotation adjustments cause the front of the base plate to rotate vertically and not cause the plate to roll.
3. Place the laser head on the mounting plate so the two front feet and rear foot line up with the corresponding holes in the mounting plate and drop into the mounting plate's miniature cross-slide assembly.
4. Secure the laser head to the mounting plate using the three leveling feet and lock nuts.

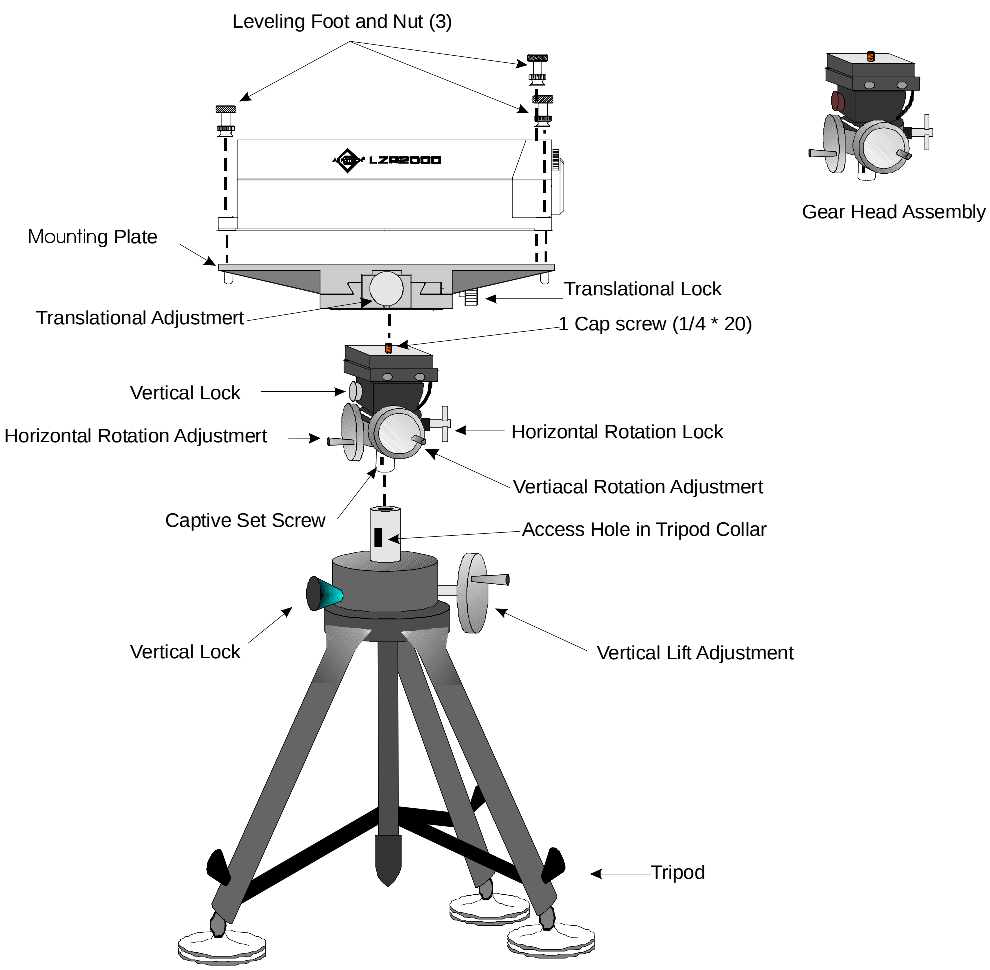


Figure 4-4. Setup of Tripod and Installation of the Laser Head

4.3.2. Tripod and Laser Head Positioning Controls

When using the tripod, every measurement made requires translational and rotational movements of the laser head. These adjustments are made often, so now is the time to become familiar with them. Laser head motion resulting from operating these controls is shown in Figure 4-5.

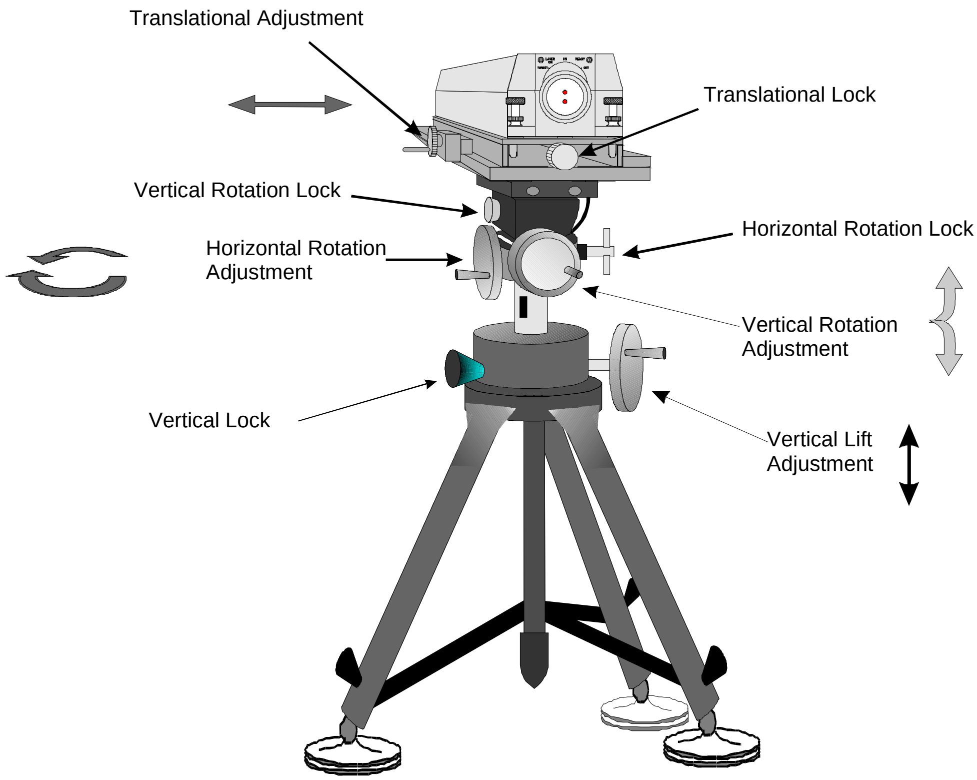


Figure 4-5. Laser Head Motions with Position Controls

For vertical translation (linear up and down movement) of the laser head, perform the following procedures.

1. Unlock vertical lock located on the tripod assembly.
2. Turn the vertical lift adjustment to raise or lower the laser head to the desired height.
3. Lock the vertical lock.

For vertical rotation (tilting) of the laser head, perform the following procedures.

1. Unlock the vertical rotation lock.
2. Turn the vertical rotation adjustment to raise or lower the laser head up or down to the desired position.
3. Lock the vertical rotation lock at the desired setting.

For horizontal translation (linear side to side movement) of the laser head, perform the following.

1. Unlock the translational lock on the mounting plate.
2. Turn the translational adjustment to slide the laser left or right to the desired position.
3. Lock the translational lock.

For horizontal rotation (turning) of the laser head, perform the following procedures.

1. Unlock the horizontal rotation lock.
2. Rotate the laser head so it points in the desired direction.
3. Lock the horizontal rotation lock after reaching the desired setting.

4.3.3. Leveling the Laser Head

Positioning one leg of the tripod in line with the laser beam in most cases will make it easier to level and align the baseplate.

Watching the bubble level on top of the tripod, adjust the leg lengths until the baseplate is level. Make these adjustments by loosing the black knobs on each leg of the tripod. Ensure the knobs are securely tightened when the leveling operation is complete.

4.4. Defining the System Layout

Before beginning the installation process, it is helpful to plan the system configuration. Understanding the precise needs of the application is vital in this endeavor. Consider the following topics to help in planning the system configuration.

- What is the purpose/goal of the application (in other words, does the application involve a measurement/control process)?
- What type of motion control system is going to be used and what types of input/output signals does it require?
- How many axes of motion are involved with the application?
- What degree of accuracy is needed?
- Does the application require the use of an external signal multiplier for higher resolution?
- Does the application require environmental compensation (i.e., temperature, pressure and humidity) for increased accuracy?
- Which components of the system will be in motion (i.e., what will be the motion axis)?
- Will the reference path and measurement path of the Laser Feedback System need to be parallel or perpendicular to each other?

Consider the desired application needs and define the required configuration accordingly.

When choosing a location for the LZR2000 System, be sure to consider such factors as the temperature and humidity extremes. The laser head (and the entire LZR2000 System) has an operating temperature range of 15-40° C and a humidity range of 0-90% (noncondensing). Also, the environment should be free of anything that could interfere with the operation of the system (such as excessive moisture, dust, or smoke). The mounting surface for the LZR2000 System should be a stable, vibration-free surface. The location should provide an electrically “clean” and stable power source for proper operation of the head (and other electrical components). In addition, the location should provide sufficient clearance for all moving parts and should allow all cables to be routed so they do not interfere with operators or moving parts.

4.4.1. Positioning the Laser Head and Tripod

Where the position of the laser will be depends on the reason for making the measurements and where the optics will be mounted. Consider the following.

- The user may want to make measurements as close as possible to the area where the tool meets the workpiece.
- The user may want to make measurements as close as possible to the system, since any offsets between the user’s measurement axis and the distance measuring system’s axis may introduce error (types of errors are discussed later in this manual).

Laser system measurements for three different axes can be made from only two setups of the laser head. Refer to Figure 4-6.

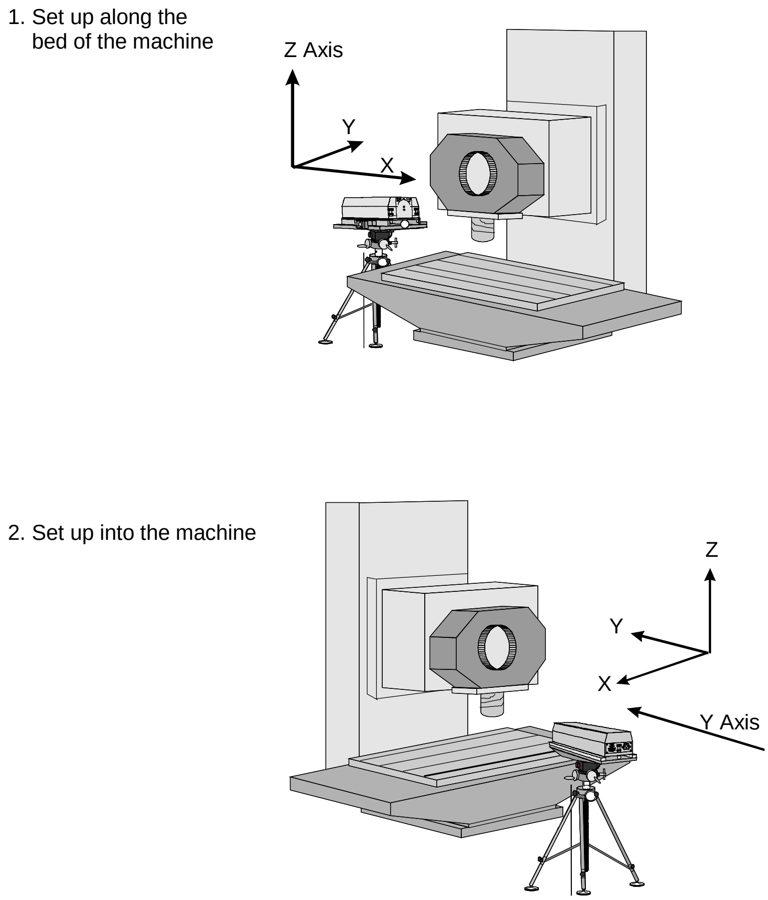


Figure 4-6. Machine Tool Positioning of Tripod and Laser

Table 4-1 illustrates what measurements can be made with the laser head set up as shown in Figure 4-6. The measurements are easily made from these two positions since:

1. All the optics have been designed around a common centerline that allows complete interchangeability for all measurements along an axis.

   For distance and angular measurements, the user can use the same mounting hardware with no adjustments between measurements.

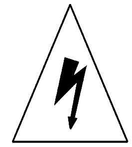
2. Measurements on the “Z” axis can be made from either the “X” or “Y” axis by turning the distance and angular interferometers on their sides or by using a turning mirror for straightness measurements (refer to the individual measurement chapters in this manual for additional information on this procedure).

Table 4-1. Measurement versus Setup Axis

Measurement	Setup Axis
Distance	
X axis	X axis or Y axis
Yaxis	X axis or Y axis
Z axis	X axis or Y axis

4.5. Supplying Power and Signal Connections to the Laser Head

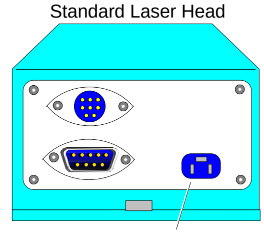
This section discusses the steps necessary to provide power to the laser head and making the signal connections between the laser head and the controller with the appropriate cable(s).



DANGER

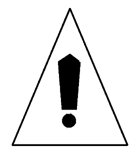
The laser head of the LZR2000 System emits laser radiation from the upper front aperture. Never stare directly into the laser beam or its reflections.

Standard Laser Head



AC Power Connector

Connecting an external power source to the standard laser head is done using a standard 6 foot (2 m) power cord that is supplied with the LZR2000 System. This keyed cable is inserted into the power connector located on the back panel of the LZR2000 laser head and connected to a 100-240 VAC source. The standard laser head uses a maximum of 50 watts of power at 100-240 VAC. To make the signal connection between the laser head and the controller, use the signal cable (typically) provided. Additional wiring information can be found in *Chapter 8: Technical Details*.



WARNING

Firmly grip any cable connector at the end (not the cord) before trying to separate a cable from its mating connector. Failure to do this may cause undo strain on the cable, damaging it internally.

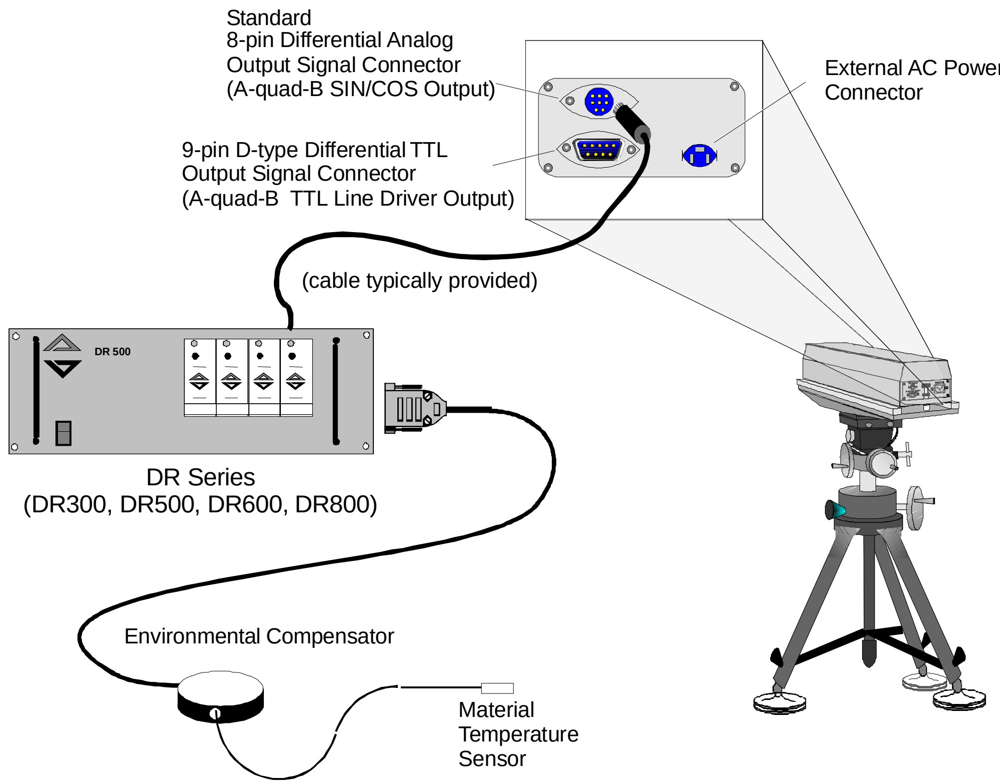


Figure 4-7. Electrical and Signal Connections

4.5.1. Environmental Compensator Connections

If an environmental compensator (LZR1100) is used, be sure to connect the supplied cable to the Misc. I/O connector of the DR300/DR500/DR600/DR800 (refer to Figure 4-7). The connectors on this cable and the mating connectors are keyed.

When attaching a remote ambient temperature sensor (LZR1020), connect the cable to the connector labeled “Temperature 1” on the LZR1100. Also, remote material temperature sensor(s) (LZR1010) can be attached in any order to the LZR1100 connector(s) labeled “Material 1”, “Material 2”, “Material 3”, or “Material 4”.

WARNING

Unlock any cable connectors before trying to separate a cable from its mating connector. Failure to do this may cause undo strain on the cable, damaging it internally.

4.6. Customized Laser Head Cables

Before positioning and aligning the system, create (if necessary) and attach all the required cables to the laser head. Standard cables are attached as described earlier. To create cables for custom applications, refer to *Chapter 8: Technical Details* for connector types and pinout information.

4.7. LZR2000 System Measurements

The LZR2000 Laser Feedback System is designed specifically to make a variety of very accurate measurements in a machine tool environment. The types of accurate measurement the Laser Feedback System can make are:

- Distance
- Velocity

The hardware, other than the optics, needed to make any measurement with the LZR2000 Laser Feedback System are a LZR2000 laser head and a feedback signal cable. This is used for all measurements made with the laser measurement system. A tripod may be needed depending on the user's application. If a tripod is not used, an alternative type of rigid support must be provided for the laser head. In addition, optical kits and other accessories are required to manipulate the laser beam for the desired measurement. Table 4-2 lists the hardware required for each measurement.

Table 4-2. Hardware versus Measurement

Measurements		
Aerotech Part & Part Number	**Linear Displacement (distance/velocity)**	**Plane Mirror**
Laser Head (LZR2000)	✓	✓
Linear Interferometer (LZR2000)	✓	
Linear Reflector (LZR2400)	✓	
Plane Mirror Optical Kit (LZR2700)		✓
Alignment Target (LZR2410)	✓	
Recommended Optional Accessories		
LZR-TRIPOD	✓	✓
Environmental Compensator (LZR1100)	✓	✓
Material Temperature Sensor (LZR1010)	✓	✓
Height adjusters (LZR1001)	✓	✓
Base Plate (LZR1002)		
Turning Mirror (LZR1003)		
Posts (AR-)	✓	✓
Storage/ Travel Case for laser head (CASE1)	✓	✓
Storage /Travel Case for Tripod (CASE2)	✓	✓
Mirror (0 degree incidence) (LZR1004)		
Mirror (45 degree incidence) (LZR1005)		
Remote Ambient Temperature Sensor (LZR1020)		
Laser Interferometer Computer System (LZR1500)		

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CHAPTER 5: LINEAR DISPLACEMENT AND VELOCITY MEASUREMENTS

In This Section:

5.1. Introduction

This chapter explains how to position and setup the required optical components of the interferometer system for linear distance and velocity measurements. The positioning process discussed in this chapter is divided into several steps. The first provides an overview of the optics, their components and their functions. The second section provides an introduction to optical accessories/aides such as height adjusters and mounting posts and their roles in positioning the optics. The third section covers the process of choosing a layout and mounting surface for the application, then mounting and positioning the optical components appropriately. The fourth section covers the process of aligning the system, from coarse alignment to the two most common methods of alignment. Each of these steps is discussed individually in the sections that follow.

5.2. Measurement Specifications and Optical Hardware

The LZR2000 Laser Feedback System is a basic system capable of measuring both velocity and linear displacement. A distance (or linear) measurement is made by measuring the change in position of one of the optics while the other is held stationary. The LZR2000 is a stand-alone product, (i.e., the product includes the necessary hardware [laser head, PC-board, software, cables, and optics]) for linear measurements. These optical components are used in linear distance and velocity measurement applications. Table 5-1 lists the required components needed for linear and velocity measurements. Besides what is listed in Table 5-1, the user may need a tripod (LZR-TRIPOD). If a tripod is not used, an alternative type of rigid support must be provided for the laser head.

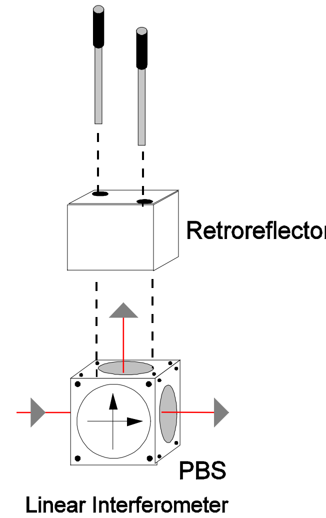
Table 5-1. Linear and Velocity Measurement Hardware List

Part Number	Description
LZR2000	Laser Head
LZR2300	Linear Interferometer
LZR2400	Linear Reflector
LZR2410 (2 each)	Alignment Target
EDU169	Manual

Table 5-2 contains the operating specifications for linear and velocity measurements. The accuracy of distance measurements are accurate within the following tolerances depending on the velocity of light compensation method and operating temperature. Values shown in Table 5-2 apply at a known material temperature with a known coefficient of thermal expansion.

Table 5-2. Linear and Velocity Operating Specifications

Accuracy			
Temp. Range	**Uncompensated**	**Compensated**	**Vacuum**
20°±1°C	±10 ppm	±1.5 ppm	±0.1 ppm
20°±5°C	±14 ppm	±1.7 ppm	±0.1 ppm
Measurement Range (Axial Separation)			
10m (33 feet)			



5.2.1. The Retroreflector

A retroreflector is an optical component that contains a single opening and has specialized internal mirrors that allow incoming laser beams to be reflected in a path that is parallel to the incident beam. One retroreflector is used by itself to reflect the measurement beam and the other retroreflector is connected to the polarized beam splitter (PBS) to reflect the reference beam. Each retroreflector has predrilled holes and knurled screws for mounting to the PBS or a height adjuster (LZR1001).

With the laser turned off, look inside the retroreflector. Notice the pattern of six connected triangles. The orientation of these triangles with respect to the incident laser beam is very important. For proper operation of the LZR2000 system, the orientation of the retroreflector is just as critical as its placement. The retroreflector must be oriented so that the incident beam strikes one of the six triangles and is reflected back from the opposite triangle. This is illustrated in Figure 5-1. If the retroreflector is not oriented properly, simply rotate the retroreflector 90 degrees.

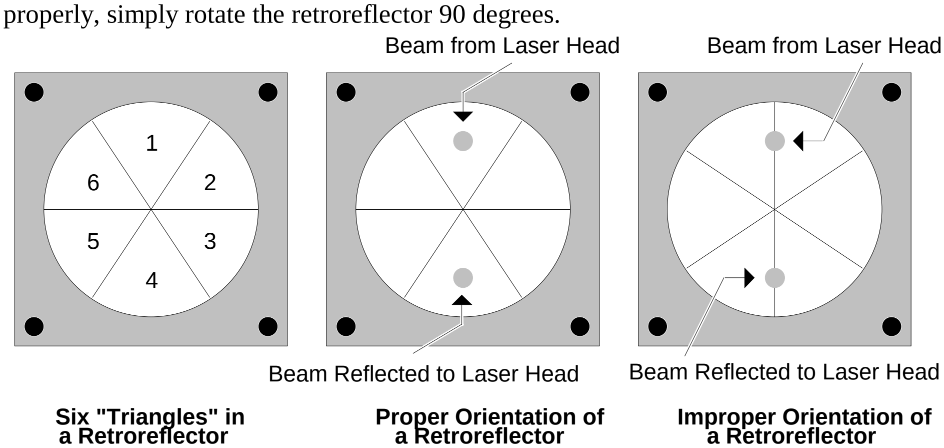
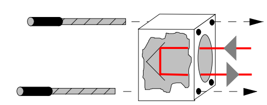
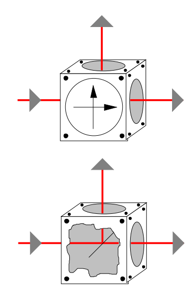


Figure 5-1. Front View of a Retroreflector



5.2.2. The PBS Cube



The PBS is a cube with four openings. Internally the PBS contains a mirrored surface at a 45° angle to the incident laser beam. This allows one component of the incident beam to be transmitted directly through the PBS and another component of the incident beam to be reflected at a 90° so that the resulting beam is perpendicular to the incident beam. One side of the PBS cube has a label that shows the direction of the incident and output beams. The PBS has predrilled holes for mounting it to a retroreflector or a height adjuster (LZR1001).

The PBS and one retroreflector are connected to form the linear interferometer (LZR2300). With the laser turned off, look inside the linear interferometer in the direction of the laser beam. Notice the pattern of six connected triangles from the retroreflector. (It may be necessary to block the exit path of the PBS with white paper in order to see the “triangles” of the retroreflector. The orientation of these triangles with respect to the PBS and incident laser beam is very important. For proper operation of the interferometer system, the orientation of the retroreflector portion of the linear interferometer is just as critical as its placement. The retroreflector must be oriented so that a portion of the incident beam is reflected by the PBS, then strikes one of the six triangles of the connected retroreflector and is then reflected back to the PBS from the opposite triangle (refer to Figure 5-1). If the retroreflector is not oriented properly, simply disconnect it from the PBS using the knurled screws and then rotate the retroreflector 90 degrees. Be sure to securely reattach the retroreflector to the PBS.

The laser beam from the LZR2000 laser head enters one aperture of the linear interferometer and hits the internal mirrored surface of the beam splitter. A polarized beam splitter (PBS) is a special optical component used to split the incident laser beam into two separate beams that are perpendicular to each other: a reference beam and a measurement beam. Refer to Figure 5-2 which shows an application where the linear interferometer is fixed and the linear retroreflector is the moving optic. This is one of several possible applications that can be seen in Section 5.4.

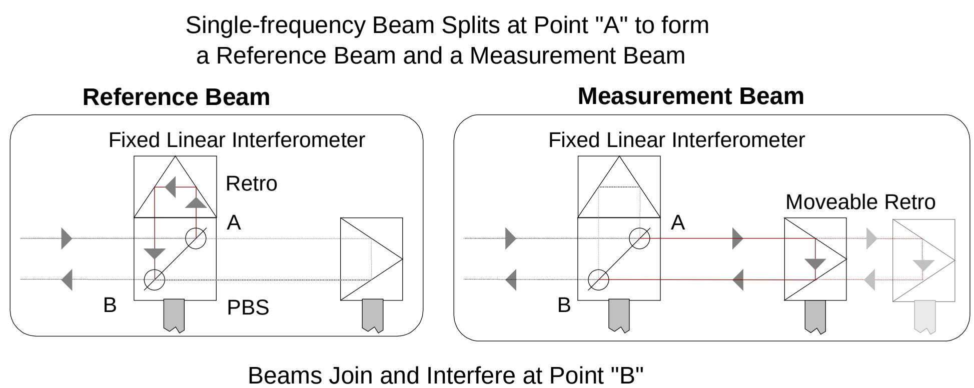
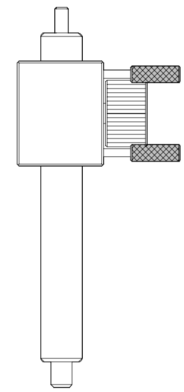


Figure 5-2. Reference and Measurement Beams

The reference beam is reflected to the retroreflector portion of the linear interferometer and is reflected back to the mirrored surface of the polarized beam splitter. Unlike the reference beam that is *reflected* from the polarized beam splitter, the measurement beam is *transmitted* through the mirrored surface of the PBS. The measurement beam travels to a moveable retroreflector and is reflected back to the PBS. At this point, the reference beam and measurement are joined and sent back to the detector portion of the laser head.

5.3. Optical Alignment Aides



Mounting hardware is available for the linear reflector and linear interferometer that allows attachment to most machine surfaces and tool spindles. This permits orientation of the optics as required. The LZR1001 (post-mount height adjuster) connects to the optical devices using a pair of knurled screws. A single larger knurled tightening knob is located on the side of the height adjuster. The knob is used to secure the height adjuster (with the connected optical component) to vertical posts that can be purchased separately.

Numerous optical posts are available with threaded ends in either standard or metric threads. These mounting posts have 8-32 threads on one end and 1/4-20 threads on the other end. Mounting post sizes, thread types, and other optical accessories are summarized in Table 5-3.

Each optic in a system requires at least one post and height adjuster. Attach the height adjuster to the side of the interferometer as shown in Figure 5-3. Then slide the height adjuster over a post supported by a base.

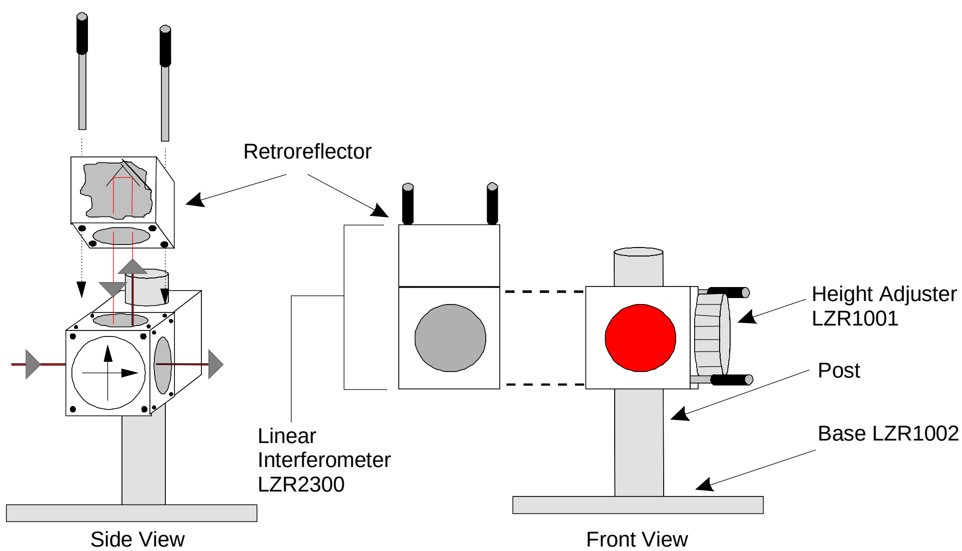


Figure 5-3. Mounting of the Interferometer

Table 5-3. Optical Mounting Accessories

Part Number	Description
AR-2	2 in (50mm)
AR-2M	2 in (50mm) (metric threads)
AR-3	3 in (75mm)
AR-3M	3 in (75mm) (metric threads)
AR-4/	4 in (100mm)
AR-4M	4 in (100mm) (metric threads)
AR-6/	6 in (150mm)
AR-6M	6 in (150mm) (metric threads)
AR-8	8 in (200mm)
AR-8M	8 in (200mm) (metric threads)
LZR1001	Post Mount Height Adjuster
LZR1002	Base Plate
LZR1003	Turning Mirror Cube (90° rotation)
LZR1004	Mirror (0 degree incidence)
LZR1005	Mirror (45 degree incidence)

5.4. Layouts and Configurations

There are several optical configurations that are available for linear measurement applications. Choose a configuration that best suits the particular application. To summarize these optical configurations, we will focus on the three fundamental components (the laser head, the linear interferometer and reflector), their orientation to the incident laser beam (i.e., parallel or perpendicular) and their relationship to the axis of motion (i.e., which component will move and what is the direction of the movement).

The interferometer is always placed in between the laser head and the two retroreflectors, refer to Figure 5-4. Normally, one of the retroreflectors will be physically attached to the interferometer and the other will be allowed to move with respect to the interferometer.

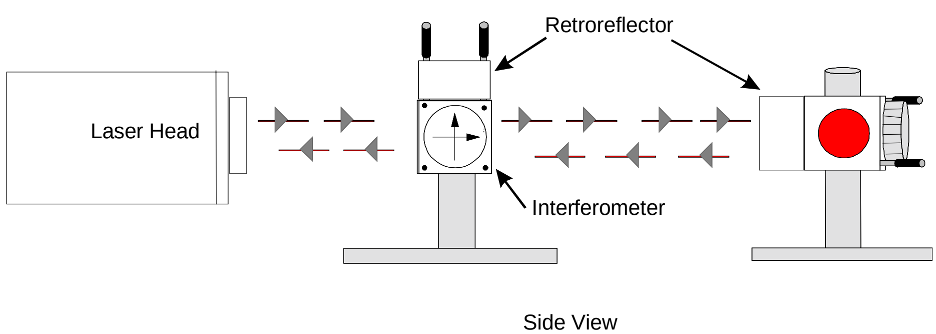


Figure 5-4. Interferometer and Retroreflector Layout

> When planning the setup, it is important that the *tail end* of one of the arrows on the interferometer's label points toward the laser head. Also, the head of each arrow must point toward a retroreflector, whether attached or moving.

The four basic optical configurations are: (1) moveable retroreflector along an axis parallel to (i.e., in line with) the incident beam, (2) moveable linear interferometer along an axis parallel to (i.e., in line with) the incident beam, (3) moveable retroreflector along an axis perpendicular to the incident beam (horizontal plane), and (4) moveable retroreflector along an axis perpendicular to the incident beam (vertical plane). These configurations are illustrated in Figure 5-5.

The optical components of the system can be mounted in a variety of ways depending on the particular application and configuration. Stationary optical components may be attached to post mount height adjusters and then secured onto mounting posts that are screwed into predrilled optical tables. Likewise, stationary optical components may be vacuum mounted to precision granite tables. Regardless of the type of mounting used, it is important to (1) begin with a surface that is flat and (2) ensure that the stationary optical component is securely mounted to that surface.

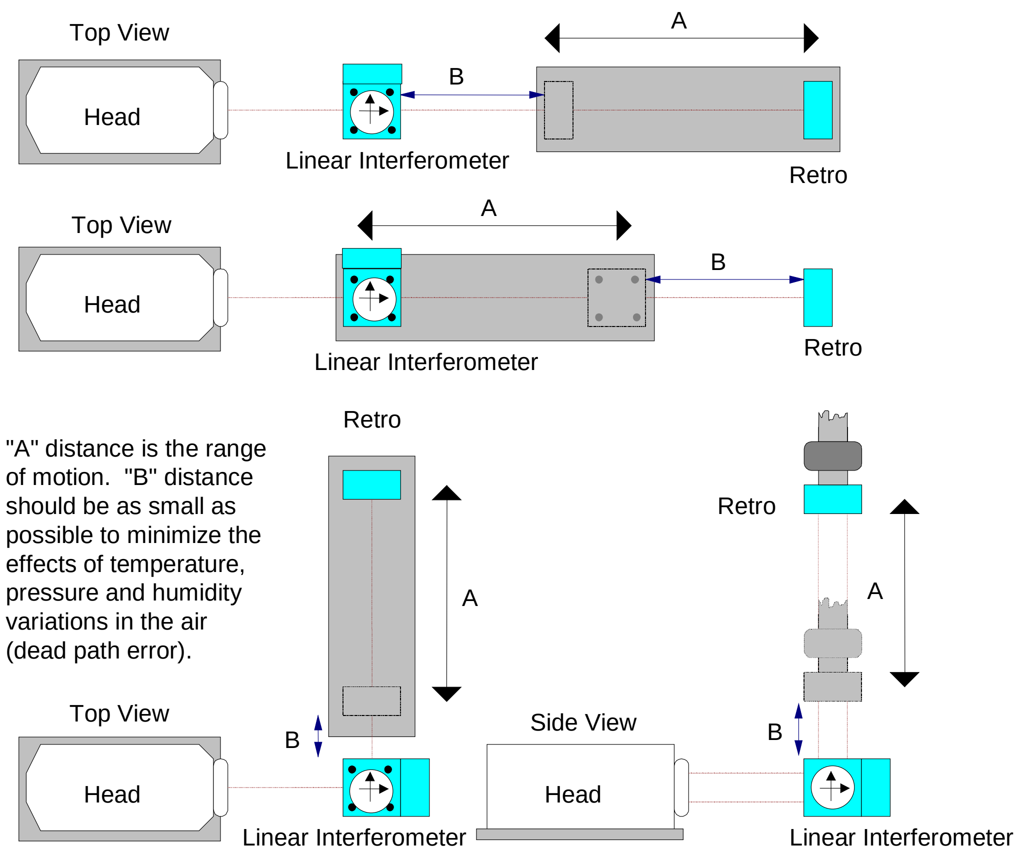


Figure 5-5. Four Basic Optical Configurations

When mounting the moveable optical component, be sure that it is securely fastened to the motion device (e.g., the stage, table or spindle). The axis of motion should be either parallel or perpendicular (as appropriate) to the incident beam.

> When aligning the optical components of the system, consider using a straight edge to aid in the coarse alignment process. This can reduce the amount of time needed to fine tune the alignment later.

There are some important considerations that must be addressed during the installation and alignment of the optics.

1. The interferometer assembly must be located between the laser head and the reflector.
2. The beam from the laser head must enter the interferometer at the tail end of one of the arrows on its label.
3. Vibrations and loose connections must be minimized by proper mounting. Avoid long extensions and make sure that all supports are completely stationary. A spindle, for example, must be secured by a brake so it won't rotate. If a brake isn't available try using a hose clamp or a wedge.
4. The laser beam must be returned to the bottom port on the laser head.
5. The optics must be aligned to the laser beam well enough to keep the cosine error at an acceptable level (see Section 5.7. Accuracy and Potential Sources of Error).
6. The optics must be aligned to the laser beam well enough to keep the beam on target at the detector.
7. If the angular optics have previously been installed, the distance optics can be installed simply by changing the optics without changing the mounting hardware.

After coarsely aligning the optical components of the system, the fine tuning process can begin. This is discussed in the next section.

5.5. Aligning the System

The alignment of the optical components of the system is accomplished visually using the laser beam of the laser head. With the optical components already coarsely aligned, supply power to the laser head using the cables discussed earlier in the previous chapter.

> The laser head of the LZR2000 System emits laser radiation from the front top aperture. Never stare directly into the laser beam or its reflections.

DANGER

It is recommended that the "Ready" LED be illuminated before beginning the alignment process. The "Ready" LED indicates that the laser has been stabilized and is ready for taking measurements. It takes approximately 15 minutes for the "Ready" LED to come on after power is supplied to the laser head.

5.5.1. Coarse Alignment

The best way to become familiar with the LZR2000 system is to use it. The following pages will lead the user through the process of getting acquainted with the system by coarsely aligning and setting up the system. The goal of this alignment process is to adjust the positions of the optical components (laser head, linear interferometer and/or reflector) such that the measurement and reference beams returning from the linear interferometer are superimposed to form a single spot that is centered on the return port of the laser head.

To set up the coarse alignment, perform the following:

1. Move the moveable part of the machine as close to the laser head as possible. This will keep the machine from hitting the laser head during a measurement and help establish the near-end-of-travel.

> The moveable part of the machine may depend on the axis being measured. Meaning, the "X" axis moveable part may not necessarily be the "Y" axis or the "Z" axis moveable part.

2. Visually align the laser head parallel to the direction of travel as well as possible and position it at an appropriate height. Some things to consider are:
   - Position for an axis appropriate for the type of measurement being made
3. Decide where to position the optics so that:
   - The interferometer is between the reflector and the laser head
   - One optic is where the tool mounts and the other is where the workpiece mounts
   - The optics are at the near-end-of-travel. This means that any subsequent motion of the machine will separate the optics further instead of bringing them closer together, refer to Figure 5-6 and Figure 5-7.
   - If measuring a perpendicular axis from the same laser head position, position the interferometer on part of the machine that remains stationary and can serve as a beginning point to measure this axis.
4. Attach the interferometer and the reflector to a height adjuster and post to accommodate the positions chosen in the previous step. Refer to Figure 5-8 and Figure 5-9.

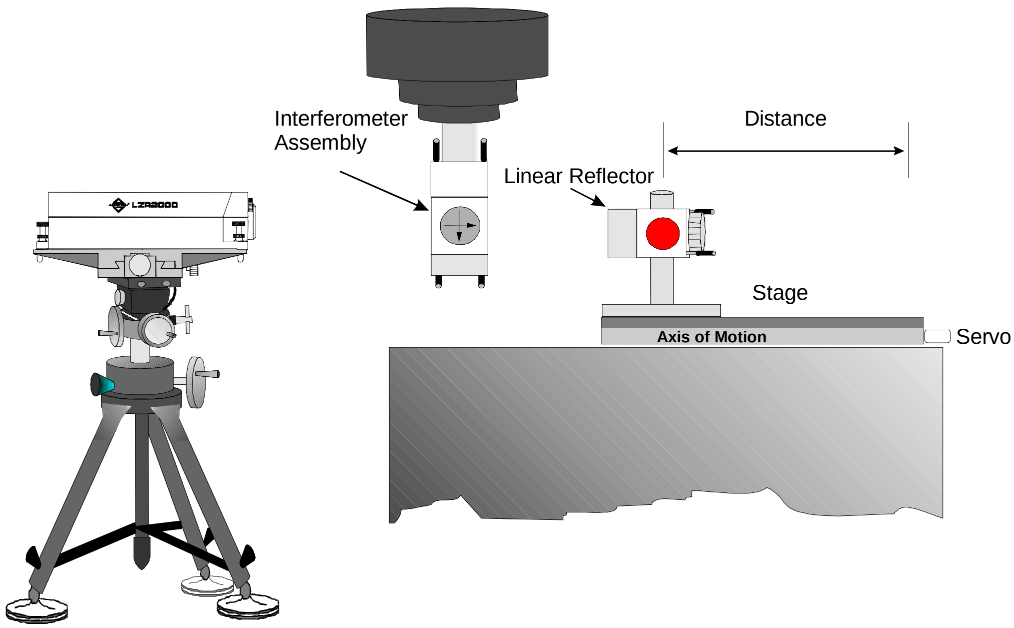


Figure 5-6. Position of Optics (Table moves)

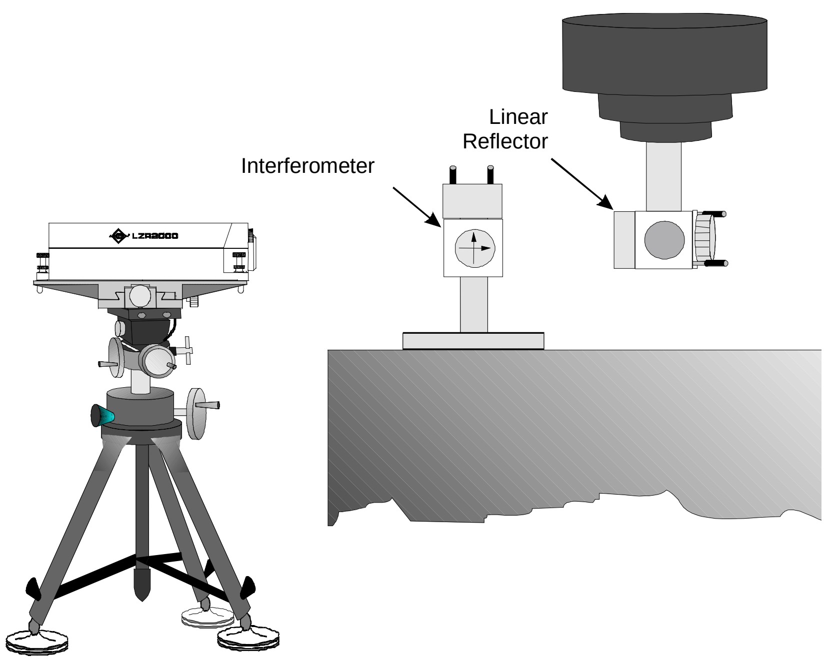


Figure 5-7. Position of Optics (Spindle moves)

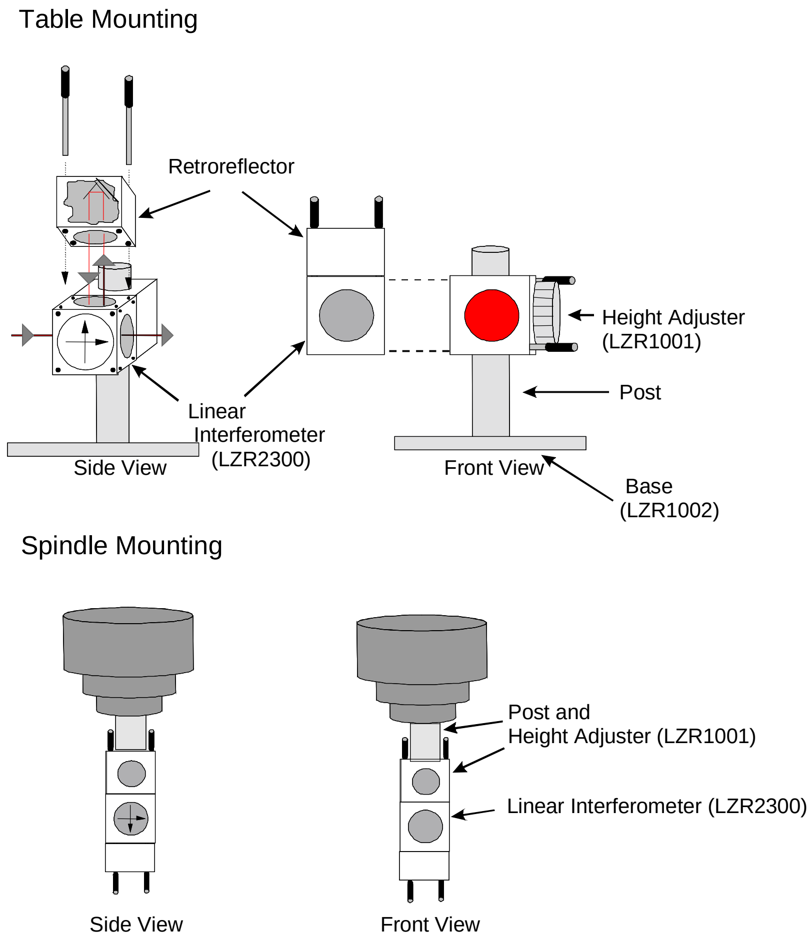


Figure 5-8. Interferometer Mounting

- If the optic is mounted in a spindle, do one of two things. Either attach the height adjuster to a post like the method for table mounting or screw the post into the height adjuster after removing the large knurled knob.
- For longer distances, it is important to reduce beam scattering, by ensuring the beam does not strike the corners of the glass in the retroreflector. This is done by mounting the retro so that its opening is facing the exit aperture of the laser head. Be sure to orient the reflector and/or the laser head so that the laser beam will hit the center of a "triangle" and be reflected to the opposite "triangle".

5. Select the small opening of the laser head's exit port by rotating the crosshairs (target) into place over the laser head's bottom (return) port.
6. Move the interferometer into the path of the laser beam while observing the front of the laser head. Adjust the position of the interferometer or the laser head so the return beam is centered on the laser head's return port target (bottom aperture).

7. Secure the entire assembly to the machine so that the interferometer is as square as possible relative to the incoming beam (pitch limitations are ±2 degrees; yaw and roll limitations are ±5 degrees). Using the post and height adjuster automatically takes care of the pitch requirement.

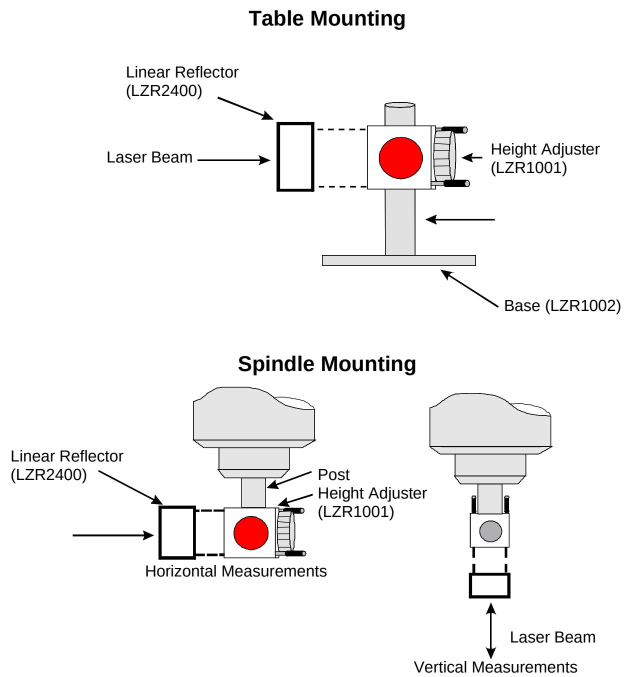


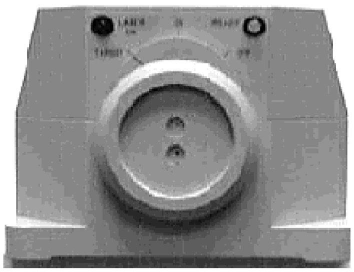
Figure 5-9. Retroreflector Mounting

8. Take the reflector and position it as close as possible to the interferometer. Observing the front of the laser head, adjust the reflector until its return beam hits the laser head's return port target. Block the laser beam path between the interferometer and reflector with a piece of paper to distinguish between the two returning beams.

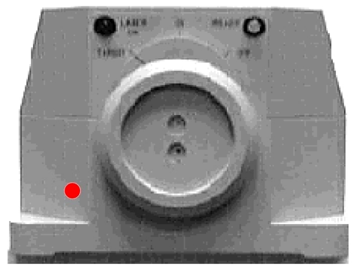
The dot that remains on the front of the laser head is the return beam from the interferometer. It may be helpful to start by lining up the edges of the reflector with those of the interferometer.

9. Secure the reflector assembly to the machine.

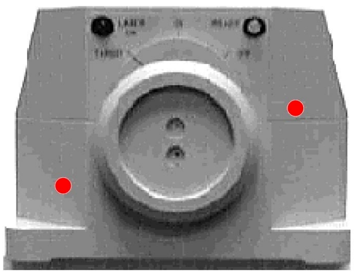
Figure 5-10 shows the front view of the laser head when the optics are in different states of alignment. In illustration A, neither beam is visible on the laser head. This can be caused by an insufficient coarse alignment or something blocking the path of the laser beam. To correct this, try adjusting the coarse positions of the individual optical components slightly.



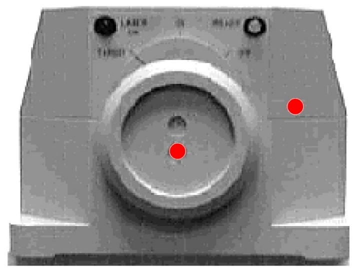
A – Beams Not Visible



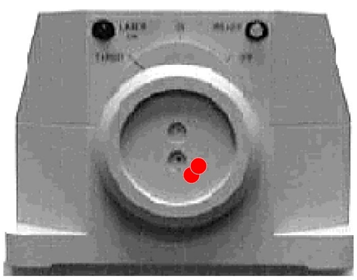
B – One Beam Is Visible



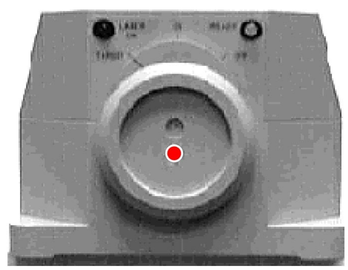
C – Beams Not Aligned or on Target



D – One Beam Is on Target



E – Both Beams Nearly Aligned



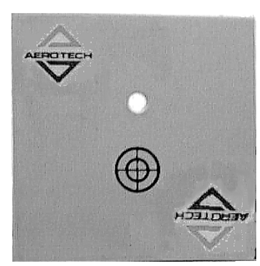
F – Both Beams Aligned

Figure 5-10. Different Degrees of Beam Alignment (View from Front of Laser Head)

To determine which optical component(s) may be out of alignment, use the supplied targets (LZR2410) to check the alignment of the optics.

1. Attach one target to the interferometer so the hole in the interferometer's target is above the target's crosshair, see Figure 5-11. Ensure that the target is positioned squarely on the interferometer, covering the opening facing the reflector (the user can use their fingers to line up the edges of the target with the bottom and side edges of the interferometer).

2. Attach the other target to the reflector so its crosshair is above the hole. Again, ensure that the target is positioned squarely on the reflector, covering the opening facing the interferometer, refer to Figure 5-11.



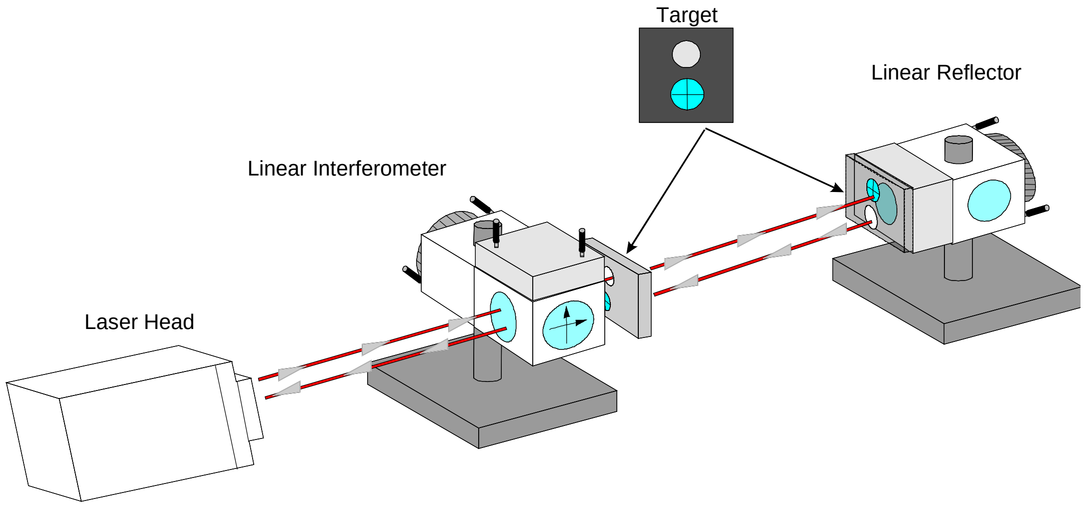


Figure 5-11. Interferometer and Retroreflector with Targets

3. Move the interferometer up or down (after loosening the height adjuster's large knob), or move the base back and forth until the laser beam passes through the hole in the interferometer's target.
4. Adjust the reflector in the same manner until the laser beam is centered on the crosshair of the reflector's target.
5. Remove the target from the reflector. Make sure the laser beam is centered on the crosshair of the interferometer's target. If necessary, adjust the reflector until it (the laser beam) is centered on the crosshair.
6. Remove the target from the interferometer, there should be two dots seen on the front of the laser head.

Checking the coarse adjustment of components in this way will typically result in at least two return beams being visible on the laser head (as in illustration C of Figure 5-10).

7. Place a piece of paper between the interferometer and the reflector in order to block the beam.

Looking at the front of the laser head, one dot should disappear. The dot that does disappear is the reflector's return beam. The dot that remains is the interferometer's return beam.

8. Adjust the interferometer's position, vertically and horizontally, until its return beam is centered on the crosshair of the lower aperture on the laser head.
9. Perform the same adjustment to the reflector until its return beam is also centered on the crosshair of the lower aperture on the laser head.

There should be only one dot visible on the lower aperture, since both beams overlap each other completely.

10. Move the reflector slightly to one side and verify that the beam remains on target.

Figure 5-12 illustrates side views of several sample optical configurations in varying degrees of alignment. Once the beams are aligned and on target, verify that the alignment remains intact for the entire range of motion of the system. Once the alignment process is complete, be careful not to bump or jar any system components, otherwise the system may need to be re-aligned.

After both beams are visible, it is usually only a matter of making fine adjustments to the components to get one beam (illustration D of Figure 5-10) aligned and on target. Making careful adjustments to the tripod (if used) and leveling screws is usually sufficient to accomplish this. The beams may be aligned such that neither beam is exactly on target as shown in illustration E of Figure 5-10. Continued adjustment of the optical components should eventually result in both beams being properly aligned and on target as shown in illustration F of Figure 5-10.

5.5.2. Fine Tuning the Alignment

The above adjustment aligned the optic's path to the laser beam. However, the normal practice is aligning the laser beam (by adjusting the laser head) to match the optics path. In any measurement made with the laser measurement system, the laser head must be aligned to the optic's or the machine's travel path. This section provides the information needed to adjust the laser head to the travel path of the optics.

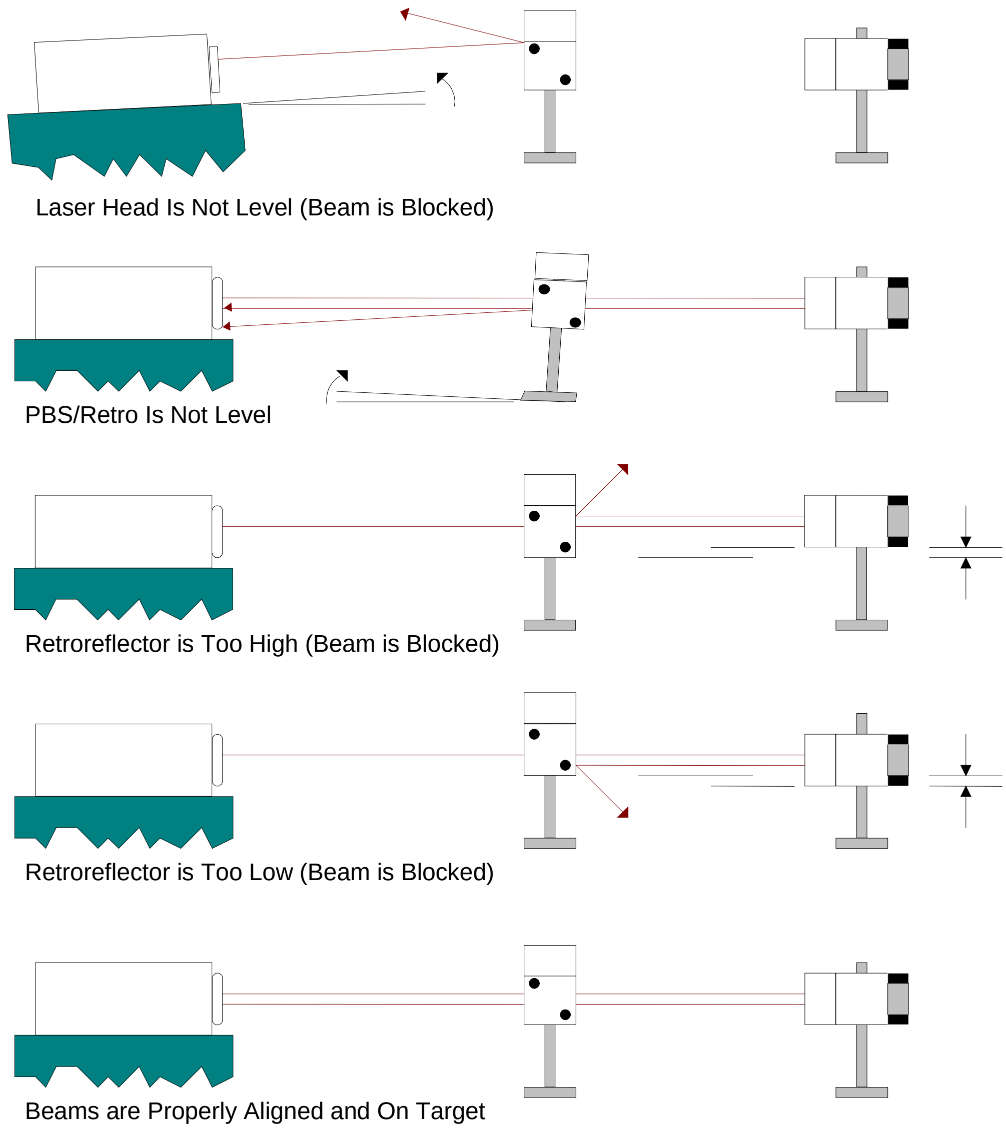


Figure 5-12. Different Degrees of Beam Alignment (Side View)

The most commonly used alignment methods are “target” and “overlapping dots.” The target method can be used for all measurement types and overlapping dots is used for only distance and velocity measurements.

Each alignment method requires translational and turning movements of the laser head. It is much easier to separate these motions into vertical and horizontal components where these adjustments will be used over and over again.

5.5.2.1. Target Method

The following alignment procedure is the target method and can be used for any measurement.

1. Attach targets to the optics as instructed in the previous coarse adjustment.

> Both optics must be at the near-end-of-travel and already adjusted around the laser beam. The near-end-of-travel means that any subsequent motion of the machine will separate the optics further rather than bring them closer together.

2. Move the reflector away from the laser. Stop the movement when the laser beam begins to move off the reflector's target, or when the optic reaches the end of travel.
3. Make a series of adjustments to the laser head until the beam returns to the crosshair on the reflector, Refer to Figure 5-13.
   a. Rotate (turn) the laser head to move the beam back toward the crosshair on the reflector. See step 2 in Figure 5-13.

> As soon as the laser head is rotated, the laser beam will be partially or fully blocked by the interferometer.

   b. Translate the laser head vertically and horizontally until the beam travels through the hole of the interferometer's target, Refer to step 3 in Figure 5-13.

> If the laser beam is not hitting the crosshair on the reflector, repeat the process of turning and translating the laser head.

4. Continue the process of moving the reflector away from the laser and adjusting the laser head as many times as necessary until the end of travel is reached. At this point the laser will be aligned to the table and the optics.

To summarize the target method, translate the laser head or move the optics in order to initially position the optics around the laser beam. After movement of one optic, rotate (tilt or turn) the laser head any time the beam does not hit the target on the reflector. Translate the laser head linearly (up/down or left/right) any time the beam does not travel through the interferometer's target hole.

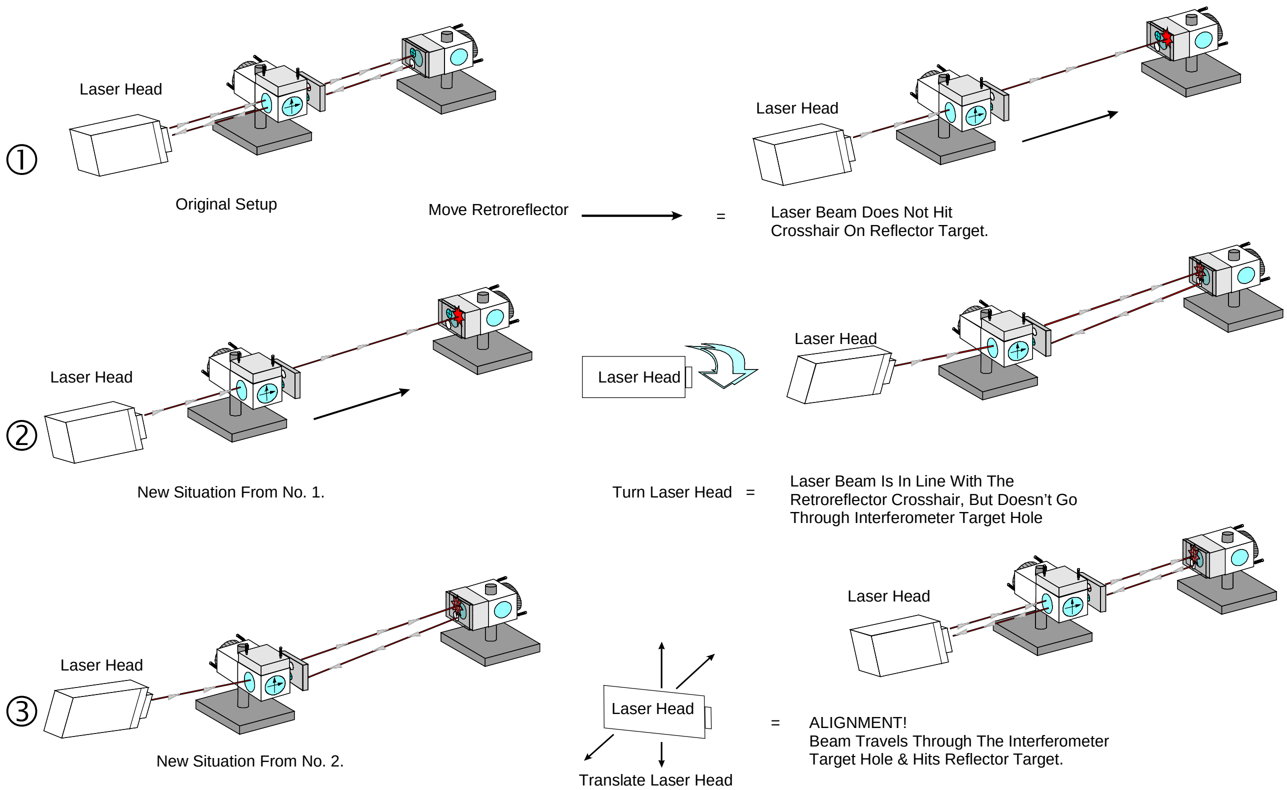


Figure 5-13. Target Alignment Process

5.5.2.2. The Overlapping Dots Method

The next method of alignment is the overlapping dots method. This process is only for distance and velocity measurements. It is identical to the target method, except that the interferometer and reflector targets are removed and the laser head return port becomes the target.

The following alignment procedure is the overlapping dot method.

1. Install the optics as instructed in the coarse adjustment.

> The return beams from both optics (the linear interferometer and the reflector) should completely overlap the laser heads lower (return) port. Set the optics at the near-end-of-travel.

2. Move the reflector away from the laser or separate the optics. If the laser beam is not aligned to the travel axis, the reflector dot will begin to move away from the return port. The dot will move until the beam is cut off by the edge of the interferometer's window.

3. Stop the movement before the beam is blocked or disappears from the front of the laser head. This step is identical to the target alignment, step 2. The exception is the laser head's return port must be viewed instead of the targets on the optics.

Figure 5-14 shows a two-dot pattern of a displaced reflector beam as the optics are moved away from the laser.

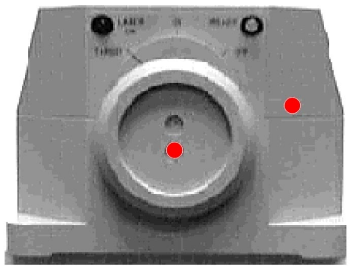


Figure 5-14. Displaced Reflector Beam

4. Make a series of adjustments to the laser head until both return beams are centered on the laser head's return port. Use the following steps to accomplish this.

Vertical Axis

a. Tilt the laser head up or down until both return dots are in line with each other. Refer to step 1 in Figure 5-15. This matches the reflector's position with this adjustment.

b. Translate the laser head up or down until the interferometer's return dot is centered on the laser head's return port. Refer to step 2 in Figure 5-15.

Performing this process maintains the interferometer's position with this adjustment.

If the dots are not in line with each other at this point, continue to repeat steps "a" and "b" until the dots are in line with each other, refer to step 2 in Figure 5-15.

Horizontal Axis

c. Turn the laser head left or right until both dots overlap. Refer to step 3 in Figure 5-15. This matches the reflector's position with this adjustment.

d. Translate the laser head left or right until both dots move to the center of the return port. Refer to step 4 in Figure 5-15. This maintains the interferometer's position with this adjustment.

If the dots separate, repeat steps "c" and "d". At the end of this procedure both dots should overlap completely at the laser head's return port. Refer to step 4 in Figure 5-15.

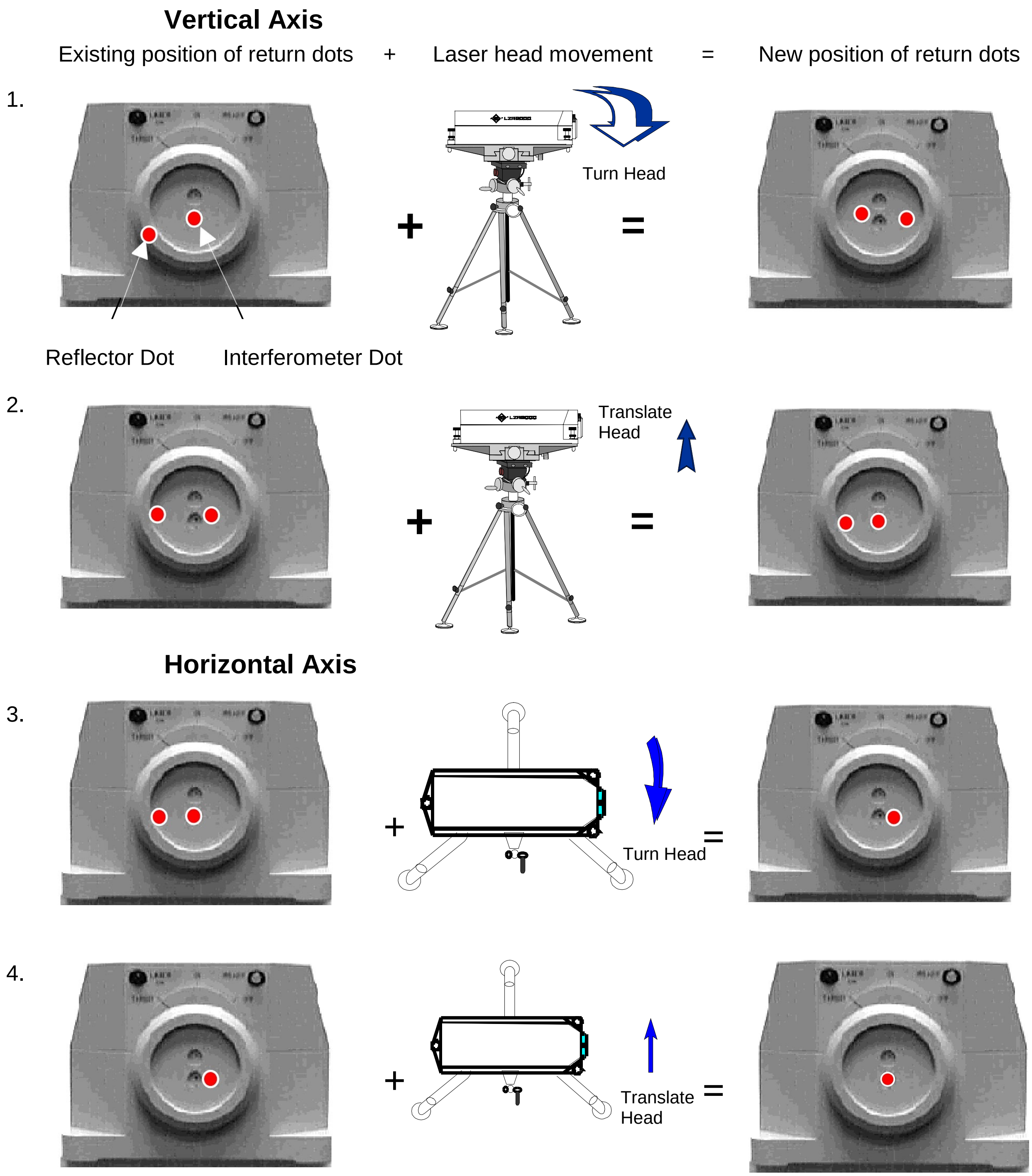


Figure 5-15. Overlapping Dots Alignment Procedure

5. After aligning, continue to move the reflector toward the end of travel. Stop and repeat the previous steps each time the reflector's return beam starts to get clipped by the interferometer, or when the end of travel is reached.

To summarize rotation and translation of the laser head, review the following:

Rotate (tilt or turn) the laser head any time the laser's beam does not hit the head's return port. Turn until both dots are in line with each other. Refer to Figure 5-16.

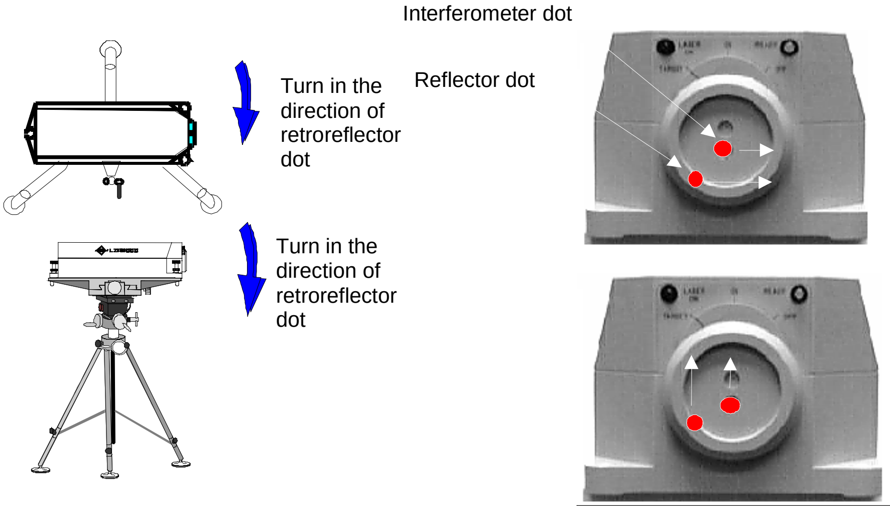


Figure 5-16. When to Rotate Laser

Translate the laser head up and down or left and right any time the interferometer return dot is not centered on the laser's return port. Refer to Figure 5-17.

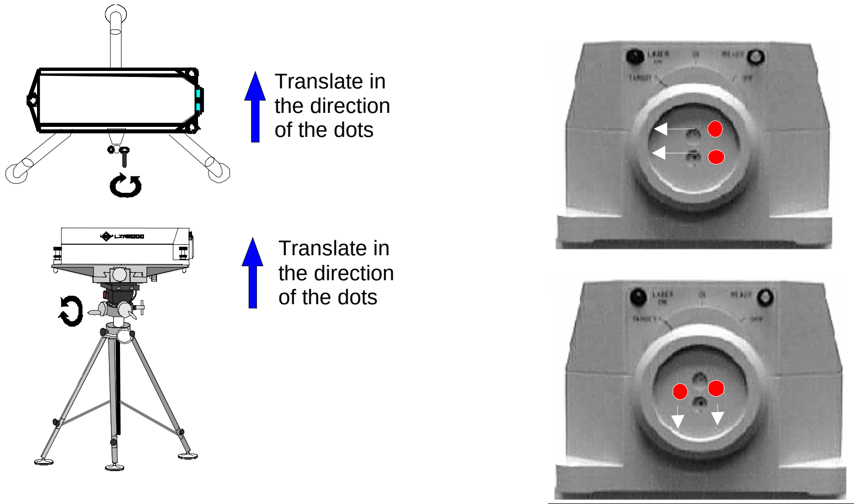
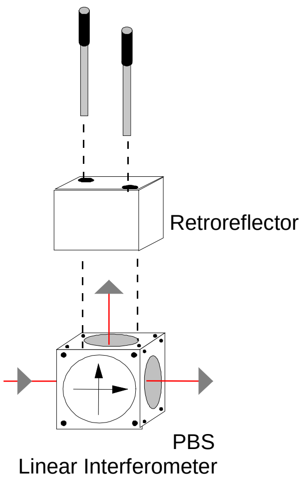


Figure 5-17. When to Translate the Laser

5.5.3. Alignment Example

The following is an alignment procedure that summarizes a linear configuration that uses a moveable measurement reflector and a stationary linear interferometer. The procedure used is “overlapping dot” method.



1. Turn on the laser and allow it to stabilize while positioning the optics. Set the shutter to the target (+) position.
2. Mount the reflector so that its opening is facing the exit aperture of the laser head. Be sure to orient the reflector and/or laser head so that the laser beam will hit the center of a “triangle” and be reflected to the opposite “triangle”.

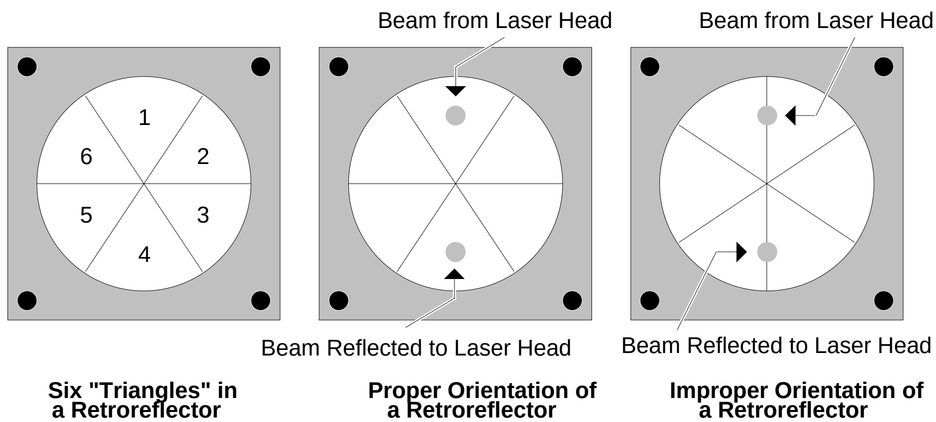


Figure 5-18. Front View of a Retroreflector

3. Position the moveable table/stage so that the reflector is at the travel limit closest to the laser head.
4. When the laser is stabilized, adjust the laser head so that the return beam hits the center of the target on the laser head.
5. Now move the table/stage so that the reflector moves to the travel limit that is furthest from the laser head. During this movement, align the head so that the return beam is always centered on the target.

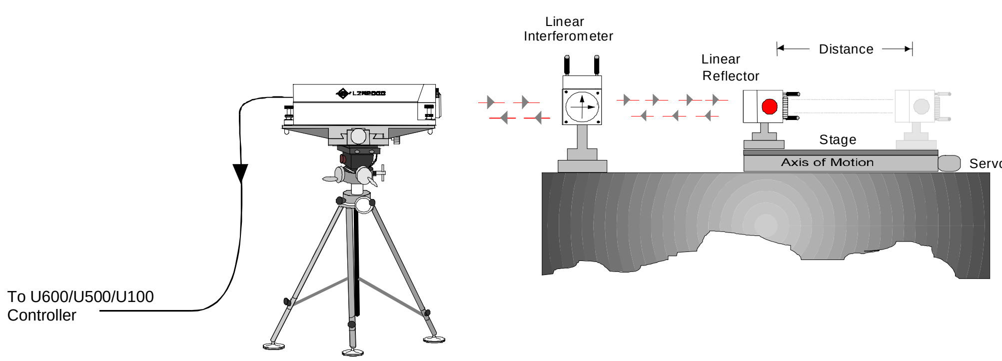


Figure 5-19. Laser Head, Interferometer, and Reflector Setup

6. Mount and position the linear interferometer on a non-moving surface between the laser head and the measurement reflector so that the beam hits the upper half of the PBS opening. The retroreflector of the linear interferometer should be oriented so that the portion of the laser beam reflected by the PBS will (1) hit the center of a "triangle", (2) be reflected to the opposite "triangle", (3) return to the PBS, and (4) be reflected back to the laser head.
7. The linear interferometer should be mounted as closely as possible to the measurement reflector. This distance should be minimized so that the measurement beam is minimally effected by air temperature, pressure and humidity differences.
8. Verify that the measurement retro does not interfere with the linear interferometer at any point in the travel range.
9. Block the transmitted beam between the interferometer and the reflector (using a piece of paper, for example) and adjust the linear interferometer assembly so that the reference portion of the return beam hits the center of the target on the laser head.
10. Remove the piece of paper and perform the same adjustment to the reflector until its return beam is also centered on the crosshair of the lower aperture on the laser head.

There should be only one dot visible on the lower aperture, since both beams overlap each other completely.

11. Confirm the system alignment by moving the measurement reflector back and forth to its limits several times. Watch that the beam position doesn't shift during the entire distance of travel.
12. Repeat the previous steps to fine tune the system further.
13. After the system is properly aligned, rotate the shutter of the laser head to the ON position. The laser interferometer is now ready for use.

For other configurations, the alignment procedure would be slightly different. Be sure to perform the alignment over the full travel range of the system to ensure consistent alignment.

5.6. Perpendicular Axis Measurements

If a measurement axis is perpendicular to the laser beam, the user should mount the interferometer in line with the laser and at the end of the axis being measured. Figure 5-20 shows the distance measurements that are perpendicular to the laser beam for each axis. Be sure the orientation of the interferometer is such that the *tail end* of one of the arrows on its (the interferometer) side is pointed toward the laser head.

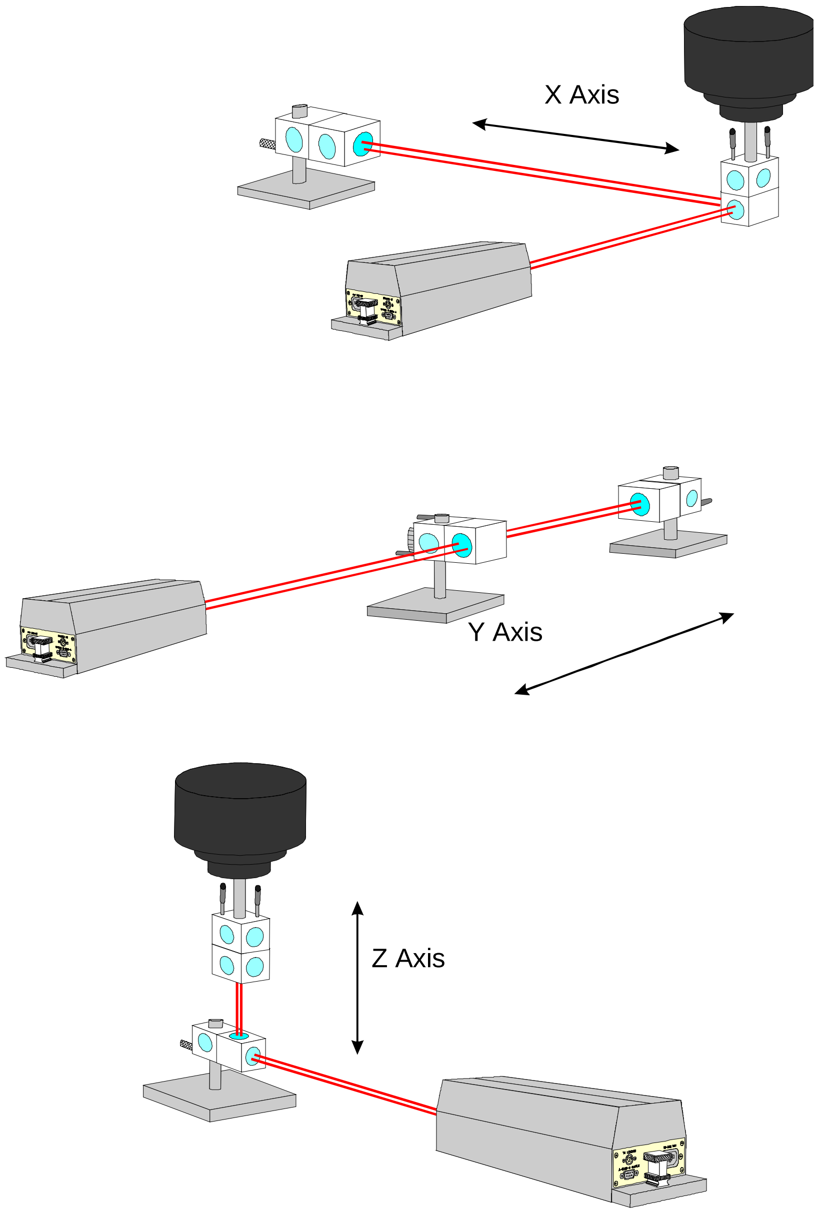


Figure 5-20. Positioning of Optics for Perpendicular Measurements

5.7. Accuracy and Potential Sources of Error

Although the LZR2000 laser system is a highly accurate and precise measurement device, the extent of its accuracy is a function of its environment and its configuration. Fluctuations in the measurement environment (i.e., temperature fluctuations, humidity changes, etc.) change the refractive index of the surrounding air, thereby affecting the wavelength of the laser beam. In addition, thermal expansion of mounting surfaces can influence the accuracy of a measurement. Misaligned system components or improper system configuration can cause operational problems and also add to the accumulated error of the system. To optimize the LZR2000 System, the introduction of these types of errors should be minimized or eliminated if possible. These sources for error are discussed individually in the sections that follow.

5.7.1. Environmental Conditions over the Measurement Span

Recall the model of the Laser Feedback System. The measurement distance is the distance between the linear interferometer and the other reflector. Refer to Figure 5-21. The laser beam travels this distance twice to determine distance measurements. During the laser beam's trip, the density of the air (through which the beam passes) is proportional to the refractive index of that air. Changes in the refractive index of this air will cause changes in the wavelength of the laser beam. These changes will ultimately affect the distance being measured. Since changes in the density of air effect the accuracy of the distance measurement, it is important to understand what conditions affect the density of air.

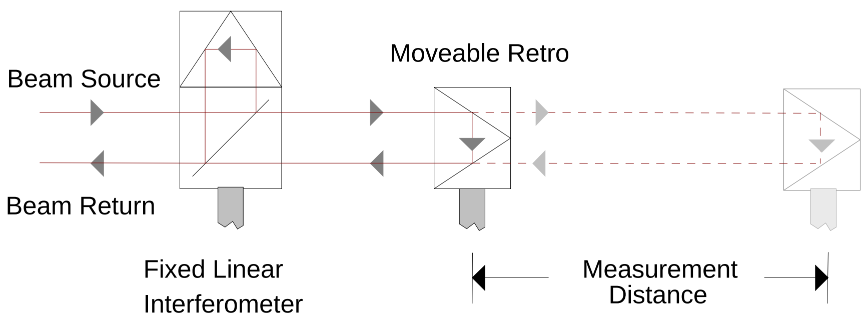


Figure 5-21. Measurement Distance of the Interferometer System

The density of air is affected by (but not limited to) air temperature, air pressure and humidity. These three factors (individually, or in combinations) can change the air density and therefore affect the accuracy of the measured distance. Table 5-4 shows these three factors and the approximate variation required by each to produce a 1 parts per million (ppm) variation in the distance measurement.

Table 5-4. Environmental Conditions Affecting Accuracy

Environmental Condition	Change	Measurement Variation
Air Temperature	-1.04° C	+1 ppm
Air Pressure	+2.7 mm Hg	+1 ppm
Humidity	-85 %	+1 ppm

In order to overcome the effects of these environmental conditions, the U600/U500 controllers provide manual or automatic ambient compensation. This gives the operator the ability to enter temperature, pressure and humidity information directly into the system for compensated readings. Otherwise, the system may be configured with the optional environmental compensation package (LZR1100). This hardware automatically sends temperature and pressure information to the motion controller for dynamic compensation. In order to accurately correct the effects of environmental and machine temperature on the laser reading, the user must place the sensors where they can accurately monitor the conditions influencing the laser. The environmental compensator (LZR1100) should always be mounted as close as possible to the actual measurement path. This is necessary in order to monitor the conditions experienced by the laser beam. When monitoring material temperature to account for material expansion, the material temperature sensor (LZR1010) should be placed on the part of the machine closest to its displacement measurement system.

The optional environmental compensation package can be used to monitor air temperature and pressure automatically. The humidity portion of the compensation is manual.

Plan the placement of the system components to avoid interference by obvious environmental forces (e.g., heating/cooling ducts, radiant heat from electrical equipment, lighting, etc.). To completely eliminate the effects of the environment, the system can be operated in a vacuum.

5.7.2. Environmental Conditions over the Length of the Dead Path

Dead path is a term that refers to the path of the laser beam between the non-moveable portion of the linear interferometer and reflector optics. Although this distance is not part of the measured distance, changes in the dead path (due to the same environmental variations discussed in the previous section) have the effect of moving the zero position (X_0). This is another possible cause of error in the system. Refer to Figure 5-22.

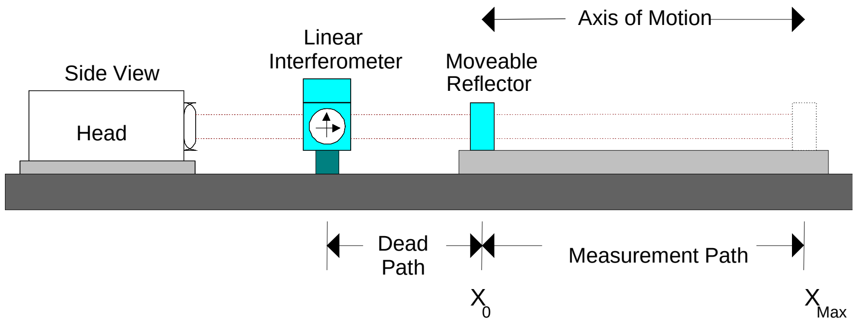


Figure 5-22. Location of the Dead Path in the LZR2000 System

As discussed in the previous section, environmental compensation can be incorporated for environmental conditions over the length of the measurement path. Unfortunately, the dead path is not part of the measurement path, therefore a separate dead path compensation is required. Dead path compensation uses the same temperature, humidity and pressure values that are used for measurement path compensation. To complete the dead path compensation calculation, the software package has an input field for manually entering the dead path distance.

Below are some guidelines used to minimize/eliminate the effects of dead path error during measurements.

- During installation of the system, be sure to position the fixed optical component as close as possible to the measurement path. In Figure 5-22, the fixed PBS/retroreflector is positioned as close as possible to the stage that is holding the moveable retroreflector. This helps to minimize the size of the dead path.
- Plan the system layout so potential heat sources (e.g., stage motors, air conditioning/heating ducts, etc.) do not directly radiate into the path of the measurement beam.
- Manually measure the distance of the dead path and include that measurement in the appropriate field of the software. The dead path distance is the total distance from the center of the linear interferometer to the center of the measurement reflector when it is at its closest travel limit (i.e., the zero position, as shown in Figure 5-22).
- Before the interferometer system is reset, always be sure to position the moveable optical component in the “near” position to minimize the size of the dead path. In Figure 5-22, the moveable reflector should be moved to the X_0 position (not the X_{Max} position) before resetting the system.
- Reset the LZR2000 System only when the optics are almost touching each other or are less than 2 inches apart. At a distance equal to or less than 2 inches, the effects due to dead path error are negligible.

Mechanical compensation is another method for minimizing dead path error. This method compensates for the dead path error by separating the PBS from the retroreflector an amount equal to the dead path. As a result, the effects of environmental factors over the dead path will be included in the second dead path (of the reference beam). Any environmental effects present over the measurement path will be incorporated into the reference path, thereby eliminating/reducing dead path error. This method is valid only if the change is uniform. Refer to Figure 5-23 and Figure 5-24.

Figure 5-24 shows an enlargement of the fixed linear interferometer after it has been separated. The components are placed a fixed distance apart. This distance must equal the dead path distance between the fixed PBS and the moveable retroreflector. The fixed components are securely held in place using a mounting post and height adjusters. The complete assembly is mounted to the bread board or optics table.

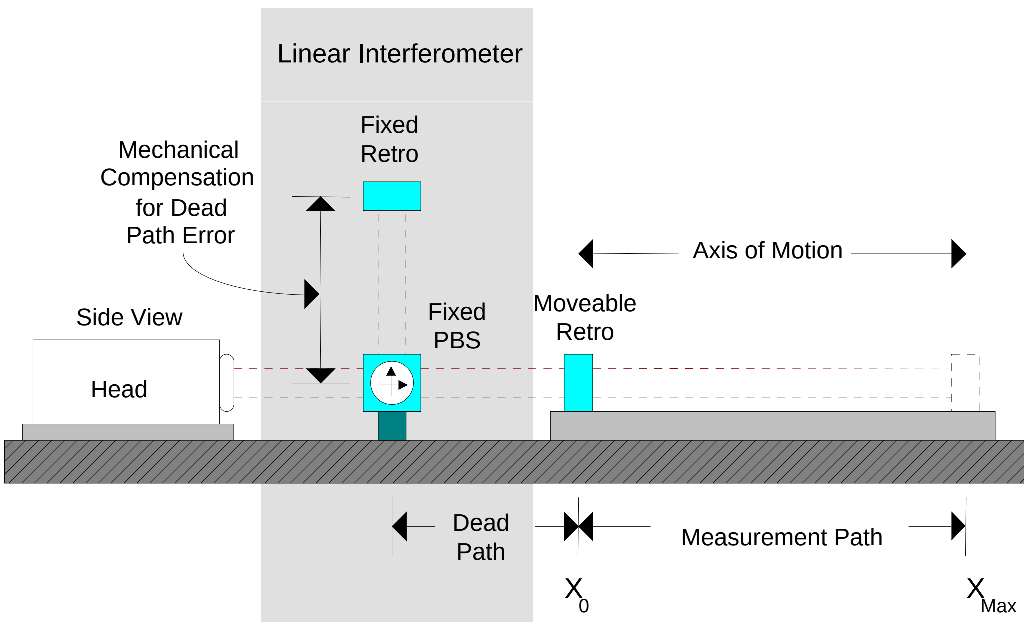


Figure 5-23. Mechanical Dead Path Compensation (System Side View)

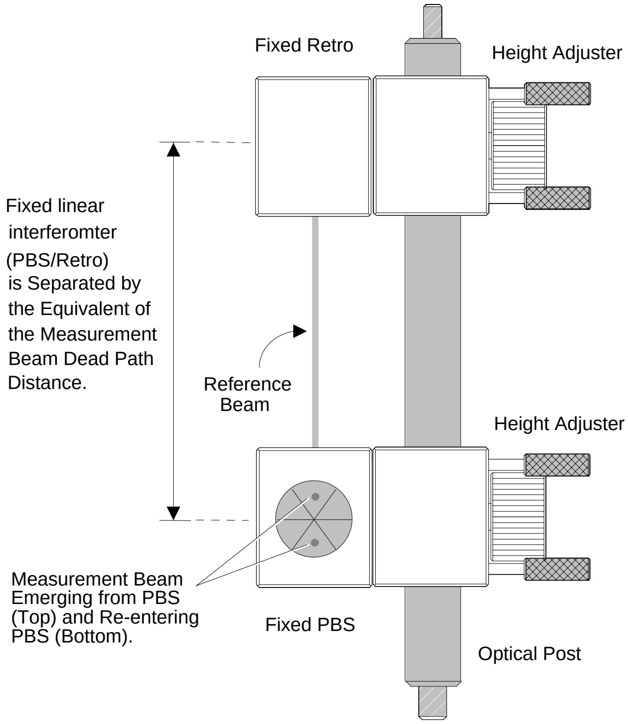


Figure 5-24. Mechanical Dead Path Compensation Close-up of Linear Interferometer Optic and Mounting Hardware (Front View)

5.7.3. Material Temperature Compensation Due to Thermal Expansion of Mounting Surfaces

As the temperatures of the system components (e.g., the stage onto which the optic is mounted, the breadboard table, etc.) change, the components themselves will expand or contract. This expansion/contraction can affect the distance that is being measured.

To compensate for the effects of thermal expansion, the LZR2000 System offers a material temperature compensation option. The U600/U500 controllers provide manual or automatic ambient compensation. This option includes four sensors (LZR1010) that can be used to measure the temperature of the materials on which they are mounted. In order to accurately correct the effects of environmental and machine temperature on the laser reading, the user must place the sensors where they can accurately monitor the conditions influencing the laser. The environmental compensator (LZR1100) should always be mounted as close as possible to the actual measurement path. This is necessary in order to monitor the conditions experienced by the laser beam. When monitoring material temperature to account for material expansion, the material temperature sensor (LZR1010) should be placed on the part of the machine closest to its displacement measurement system.

> If the material compensation option is used, then up to four temperature sensors may be used. If more than one sensor is used, the temperatures are averaged into a single temperature value. This averaged value is then used to calculate the appropriate compensation value.

5.7.4. Measurement Axis and Travel Axis Alignment (Cosine Error)

Depending on the configuration, the mechanical axis (i.e., the axis of motion) and the travel axis of the laser beam should be either parallel or perpendicular to each other. Refer to Figure 5-5 on page 5-7. If these two axes are misaligned, then the two distances will be slightly different. This difference represents an error that is a function of the angle of misalignment between the two axes (specifically, the cosine of this offset angle) and the path of the laser beam. For this reason, this type of error if called Cosine error. Refer to Figure 5-25.

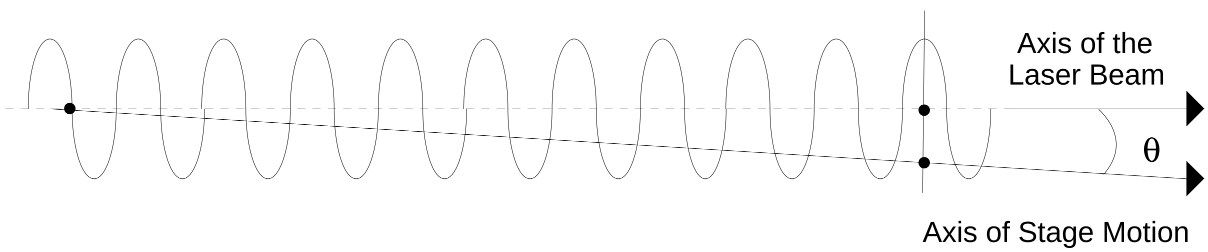


Figure 5-25. Illustration of Cosine Error

To reduce the effects of cosine error, the motion axis of the reflector must be parallel (or perpendicular depending on the configuration) to the path of the laser beam. If these axes are misaligned, then the distance being measured by the LZR2000 System will be the distance offset by the angle θ. Careful beam angle pitch and yaw adjustments may be necessary to maximize accuracy and minimize the effects of cosine error.

5.7.5. Abbé Error

Abbé error is a linear error (e.g., an incorrect distance measurement) that is caused by an angular error (e.g., a deviation in the motion surface) and is represented mathematically as the difference between the measured distance and the actual distance moved. Abbé error is introduced into the LZR2000 System when the motion surface (e.g., the stage table) has a yaw curvature, for example. As a result of this curvature, an angular error will exist between the reported position of the stage (from an encoder, for example) and the measured distance from the interferometer. Refer to Figure 5-26.

The effects of Abbé error can be minimized by reducing the angular error in the motion surface (i.e., by ensuring flatness, straightness, etc.). This can be accomplished by using laser interferometry and hardware such as special optics and LVDT sensors to measure pitch, yaw, straightness, flatness, etc. Abbé error could be virtually eliminated by mounting an LVDT (or similar touch probe) directly to the measurement reflector. Other ways to minimize the effects of Abbé error include:

- use precision mechanical components for motion
- keep the measurement device (i.e., the measurement reflector) centered on the axis of stage motion
- use mechanical components with air bearings
- use precision ground mounting surfaces (granite tables, etc.)
- do not extend the measurement device beyond the base of the mounting surface over the range of motion.

In Figure 5-26, the stage table has an exaggerated yaw curvature. Although the stage table moves in a path that is parallel to the laser beam path, the stage table (and the measurement reflector which is mounted on it) is not perpendicular to the laser path. The amount of linear error in the measurement path due to this angular error is the Abbé error.

As the enlarged drawing illustrates, as the linear interferometer is placed further away from the center axis of stage motion (see cutaway view), the measurement inaccuracy increases due to Abbé error.

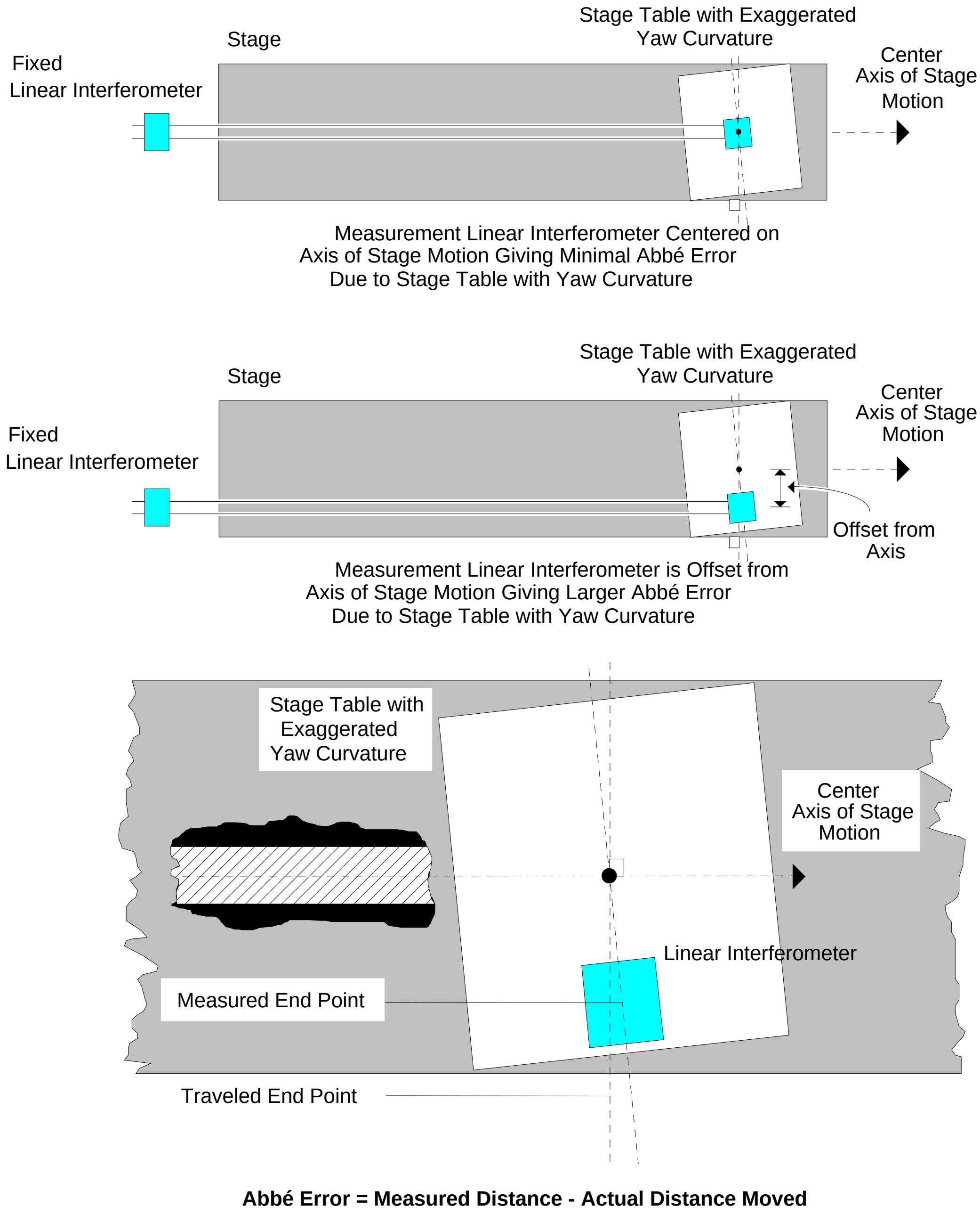


Figure 5-26. Illustration of Abbé Error

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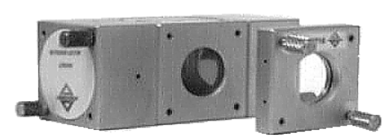
CHAPTER 6: PLANE/FLAT MIRROR MEASUREMENTS

In This Section:

6.1. Introduction

This chapter explains how to position and setup the required optical components of the interferometer system for plane/flat mirror measurements. These measurements are commonly found in X-Y stage applications where movement perpendicular to the laser axis is limited in traditional retroreflector (linear) measurement optics. The positioning process discussed in this chapter is divided into two steps. The first provides an overview of the process of choosing a layout and mounting surface for the application, then mounting and positioning the optical components appropriately. The second step covers the process of aligning the system.



6.2. Measurement Specifications and Optical Hardware

The LZR2000 Laser Feedback System is a system capable of making plane/flat mirror measurements. A plane/flat mirror measurement is made by measuring the change in position of one of the optics (the mirror) while the other is held stationary. These optical components are used in linear distance and velocity measurement applications. Table 6-1 lists the required components needed for plane/flat mirror measurements. Besides what is listed in Table 6-1, the user may need a tripod (LZR-TRIPOD). If a tripod is not used, an alternative type of rigid support must be provided for the laser head.

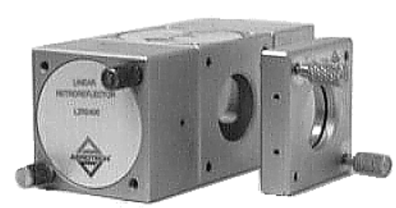


Table 6-1. Plane/Flat Mirror Measurement Hardware List

Part Number	Description
LZR2000	Laser Head
LZR2700	Plane/Flat Mirror Optical Kit
LZR2720	Plane Mirror (optional)
EDU169	Manual

Table 6-2 contains the operating specifications for plane/flat mirror measurements. Because of the optical configuration, resolution is half that of linear displacement measurements using a single reflector, compare to Table 6-2. Distance measurements are accurate within the following tolerances depending on the velocity of light compensation method and operating temperature. Values shown in Table 6-2 apply at a known material temperature with a known coefficient of thermal expansion.

Table 6-2. Plane/Flat Mirror Operating Specifications

Accuracy			
Temp. Range	**Uncompensated**	**Compensated**	**Vacuum**
20°±1°C	±10 ppm	±1.5 ppm	±0.1 ppm
20°±5°C	±14 ppm	±1.7 ppm	±0.1 ppm
Measurement Range (Axial Separation)			
5m (16.5 feet)			

Since alignment of these optics is much more sensitive then for linear optics, linear optics are recommended for general use.

6.3. Layouts and Configurations

There are several optical configurations that are available for plane/flat mirror measurement applications. Choose a configuration that best suits the particular application. To summarize these optical configurations, we will focus on the three fundamental components (the laser head, the plane/flat optical kit and mirror), their orientation to the incident laser beam (i.e., parallel or perpendicular) and their relationship to the axis of motion (i.e., which component will move and what is the direction of the movement).

The interferometer is always placed in between the laser head and the mirror, refer to Figure 6-1. The interferometer will be physically attached to the spindle or stage and the mirror will be allowed to move with respect to the other optic.

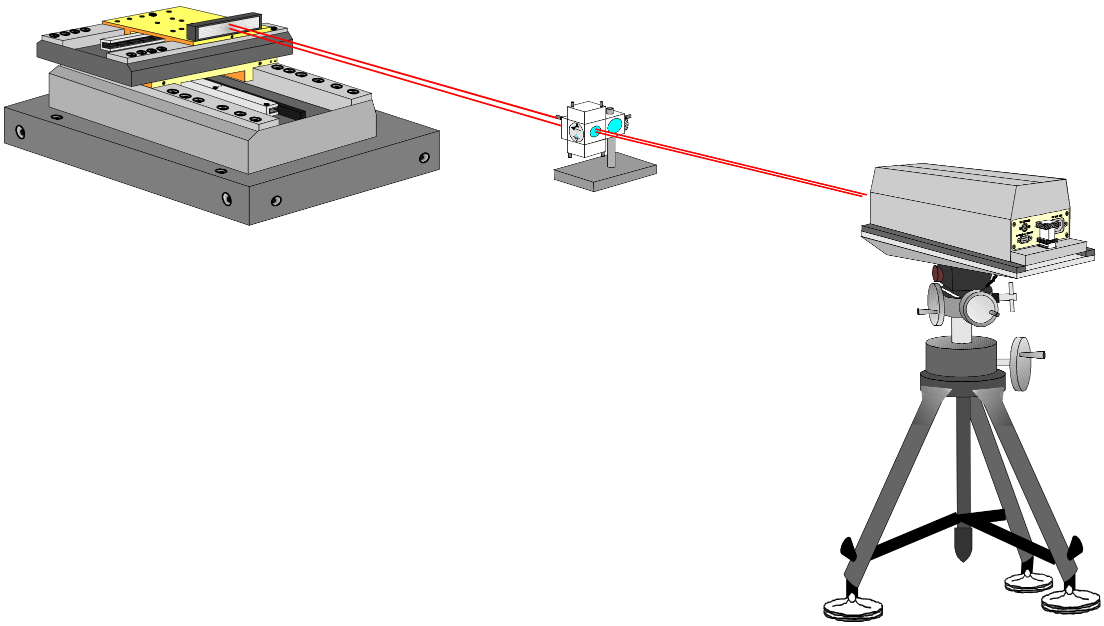


Figure 6-1. Plane/Flat Mirror Layout

> The interferometer, as compared to the interferometer in the straightness measurement, must remain stationary and the mirror is the moving optic.

IMPORTANT

> When planning the setup, it is important that the *tail end* of one of the arrows on the interferometer's label points toward the laser head.

The interferometer may be attached to post-mount height adjusters (LZR1001) and then secured onto mounting posts that are screwed into predrilled optical tables. Likewise, stationary optical components may be vacuum mounted to precision granite tables. Regardless of the type of mounting used, it is important to (1) begin with a surface that is flat and (2) ensure that the stationary optical component is securely mounted to that surface.

When mounting the mirror, be sure that it is securely fastened to the motion device (e.g., the stage, table or spindle). The axis of motion should be either parallel or perpendicular (as appropriate) to the incident beam. The mirror used in the plane/flat mirror measurement can be either the LZR2720 (Plane Mirror) or some other laser grade quality mirror. Custom mirrors can be purchased by contacting any Aerotech sales representative.

> When aligning the optical components of the system, consider using a straight edge to aid in the coarse alignment process. This can reduce the amount of time needed to fine tune the alignment later.

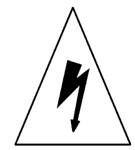
There are some important considerations that must be addressed during the installation and alignment of the optics.

1. The plane/flat mirror optical assembly (linear interferometer and one retroreflector) must be located between the laser head and the mirror.
2. The beam from the laser head must enter the interferometer at the tail end of one of the arrows on its label.
3. Vibrations and loose connections must be minimized by proper mounting. Avoid long extensions and make sure that all supports are completely stationary. A spindle, for example, must be secured by a brake so it won't rotate. If a brake isn't available try using a hose clamp or a wedge.
4. The laser beam must be returned to the bottom port on the laser head.
5. The optics must be aligned to the laser beam well enough to keep the cosine error at an acceptable level (see Section 5.7. Accuracy and Potential Sources of Error).
6. The optics must be aligned to the laser beam well enough to keep the beam stationary on the target.

After coarsely aligning the optical components of the system, the fine tuning process can begin. This is discussed in the next section.

6.4. Aligning the System

The alignment of the optical components of the system is accomplished visually using the laser beam of the laser head. With the optical components already coarsely aligned, supply power to the laser head using the cables discussed earlier in Chapter 4.


DANGER

> The laser head of the LZR2000 System emits laser radiation from the front top aperture. Never stare directly into the laser beam or its reflections.

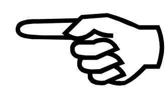
It is recommended that the “Ready” LED be illuminated before beginning the alignment process. The “Ready” LED indicates that the laser has been stabilized and is ready for taking measurements. It takes approximately 15 minutes for the “Ready” LED to come on after power is supplied to the laser head.

6.4.1. Coarse Alignment Process

The following pages will lead the user through the process of getting acquainted with plane/flat mirror measurements by coarsely aligning and setting up the system. The goal of this alignment process is to adjust the positions of the optical components (laser head, interferometer and/or mirror) such that the beams returning from the interferometer are superimposed to form a single spot that is centered on the return port of the laser head.

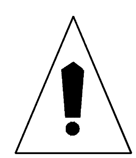
To set up the coarse alignment, perform the following:

1. Move the moveable part of the machine as close to the laser head as possible. This will keep the machine from hitting the laser head during a measurement and help establish the near-end-of-travel.



> The moveable part of the machine may depend on the axis being measured. Meaning, the “X” axis moveable part may not necessarily be the “Y” axis or the “Z” axis moveable part.

2. Visually align the laser head parallel to the direction of travel as well as possible and position it at an appropriate height.


IMPORTANT

> Before aligning the laser head to the mirror, the interferometer optics must be in place (between the laser head and the mirror). If it is not, all direct reflections returning from the mirror will enter the laser head’s exit port instead of the return port causing the laser head to become unstable.

3. Decide where to position the optics so that:
   - The interferometer is between the plane/flat mirror and the laser head
   - The interferometer is where the tool mounts and the mirror is where the workpiece mounts

- The optics are at the near-end-of-travel. This means that any subsequent motion of the machine will separate the optics further apart instead of bringing them closer together. Refer to Figure 6-2.
- If measuring a perpendicular axis from the same laser head position, position the interferometer on the part of the machine that remains stationary and can serve as a beginning point to measure the axis. Refer to Figure 6-3 and Figure 6-4.

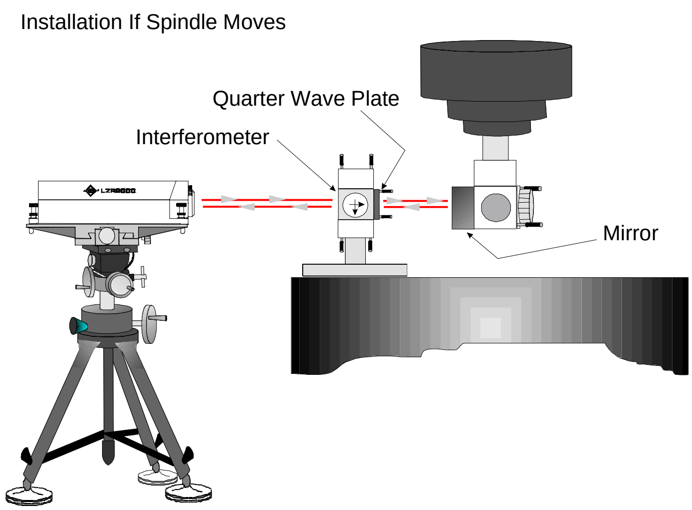


Figure 6-2. Position of Plane/Flat Optics (Spindle Moves)

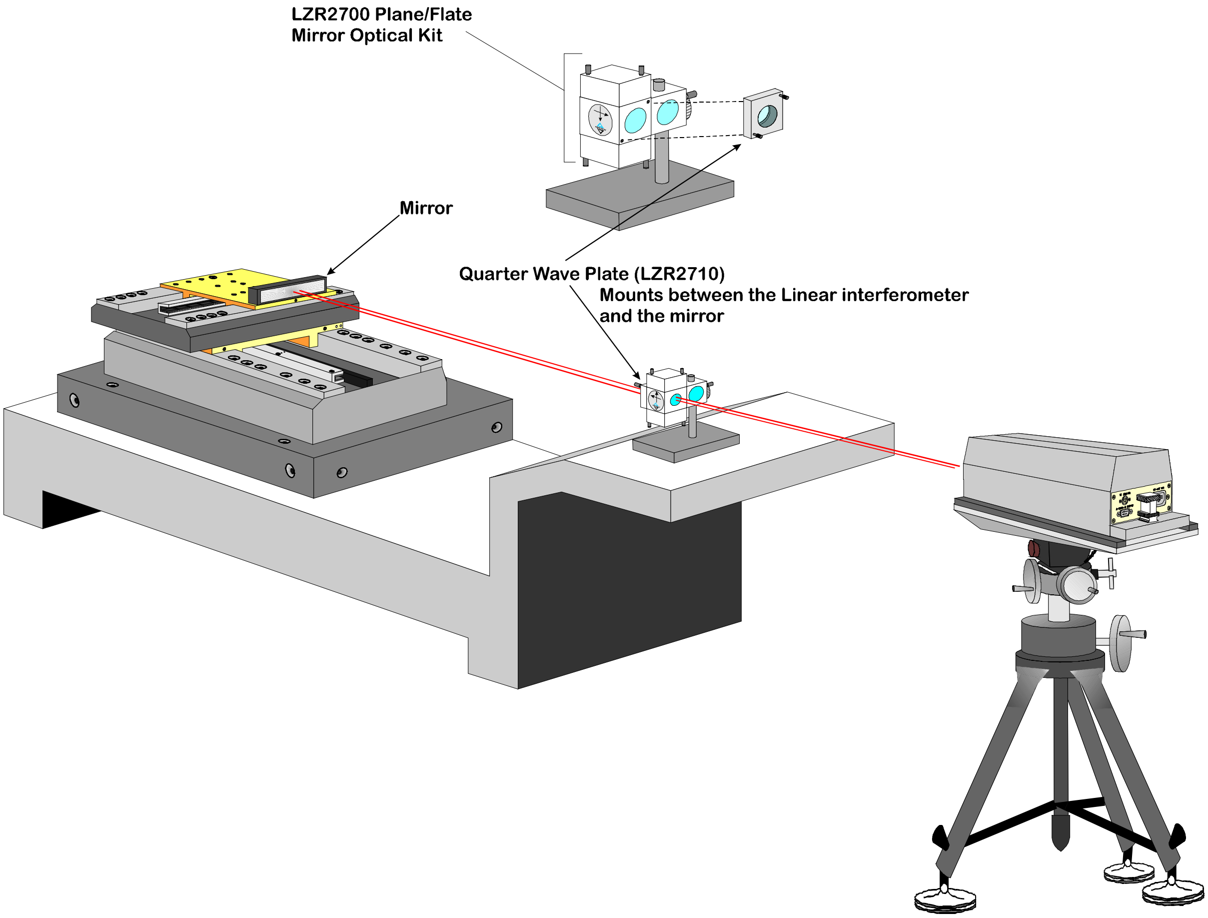


Figure 6-3. Plane/Flat Mirror Measurement

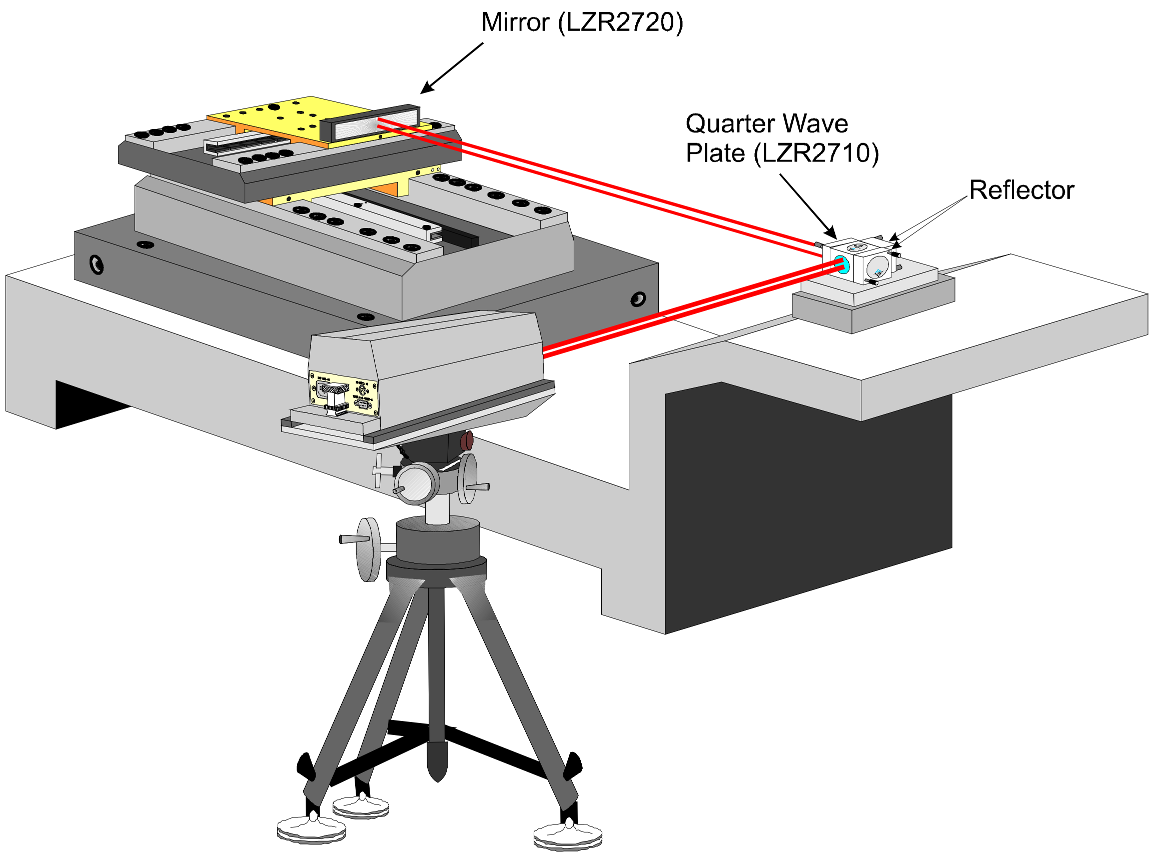


Figure 6-4. Perpendicular Plane/Flat Mirror Measurement

4. If not already attached, mount the quarter wave plate (LZR2710) on the front of the linear interferometer, see Figure 6-4 and Figure 6-6.
5. Be sure to orient the reflector and/or laser head so that the laser beam will hit the center of a "triangle" and be reflected to the opposite "triangle". See Figure 6-5.

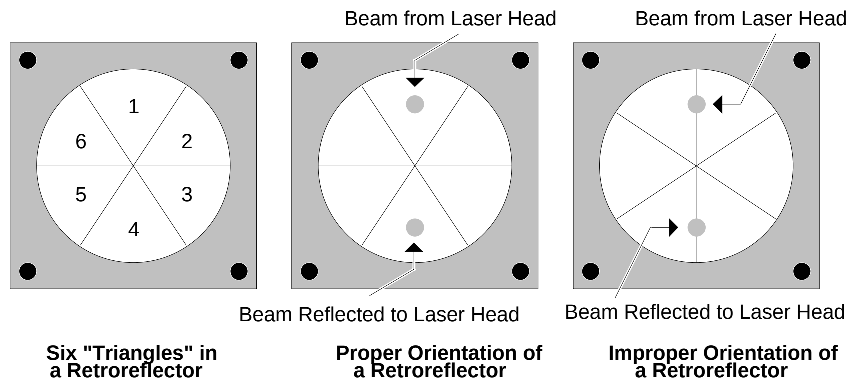


Figure 6-5. Front View of a Retroreflector

The quarter wave plate (LZR2710) must be between the mirror and the interferometer (orientation is not important).

6. Attach the interferometer to a height adjuster and post to accommodate the position chosen in the previous step. Refer to Figure 6-6. Attach the mirror to the moving stage or device.
    - If the optic is mounted on a table, support the post with a base.

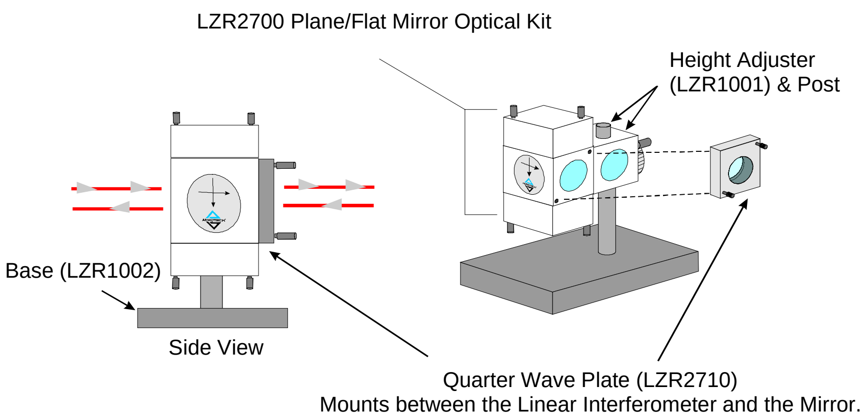


Figure 6-6. Plane/Flat Mirror Optics Mounting

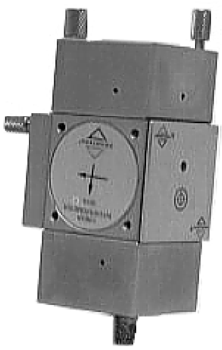
- If the optic is mounted in a spindle, do one of two things. Either attach the height adjuster to a post like the method for table mounting or screw the post into the height adjuster after removing the large knurled knob.

7. Select the small opening of the laser head's exit port by rotating the crosshairs (target) into place over the laser head's bottom (return) port.
8. Attach the target to the interferometer (refer to Figure 6-7). The target is included with the optics package.

Make sure the target is squarely positioned relative to the edges of the center optic. If needed, use finger tips to match edges.

9. Move the interferometer (or translate the laser head) so the beam passes through the target's hole.
10. Secure the entire assembly to the machine so that the interferometer is as square as possible relative to the incoming beam (pitch limitations are ±2 degrees; yaw and roll limitations are ±5 degrees). Using the post and height adjuster automatically takes care of the pitch requirement.

11. Remove the target from the interferometer.



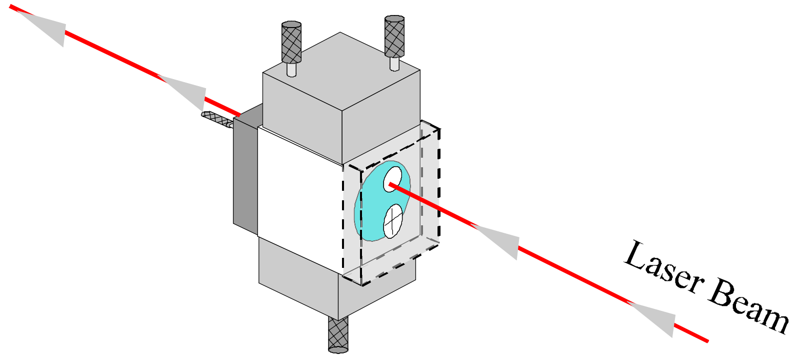


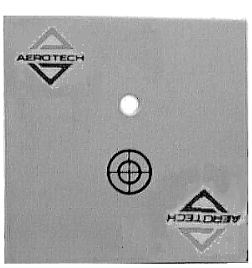
Figure 6-7. Attachment of Target to Interferometer (Plane/Flat Measurement)

12. Take the mirror and position it as close as possible to the interferometer. Watching the front of the laser head, adjust the mirror until the return beams hit the laser head's return port target.

> The return beams from both optics (the linear interferometer and the mirror) should completely overlap the laser heads lower (return) port.

To determine which optical component(s) may be out of alignment, use the supplied target to check the alignment of the optics.

13. Reattach the target to the interferometer (see Figure 6-7).
14. Move the interferometer up or down (after loosening the height adjuster's large knob), or move the base back and forth until the laser beam passes through the hole in the interferometer's target. Remove the target from the interferometer, there should be two dots seen on the front of the laser head.



15. Adjust the mirror. Make sure the laser beam is centered on the crosshair of the interferometer's target. If necessary, adjust the mirror until it (the laser beam) is centered on the crosshair.
16. Adjust the interferometer's position, vertically and horizontally, until its return beam is centered on the crosshair of the lower aperture on the laser head.
17. Perform the same adjustment to the mirror until its return beam is also centered on the crosshair of the lower aperture on the laser head.

There should be only one dot visible on the lower aperture, since both beams overlap each other completely.

18. Make sure that the beam position is fixed on the target.

Once the beams are aligned and on target, verify that the alignment remains intact for the entire range of motion of the system. Once the alignment process is complete, be careful not to bump or jar any system components, otherwise the system may need to be re-aligned.

After both beams are visible, it is usually only a matter of making fine adjustments to the components to get the beam aligned and on target. Making careful adjustments to the tripod (if used) and leveling screws is usually sufficient to accomplish this.

6.4.2. Fine Tuning the Alignment

The above adjustment aligned the optic's path to the laser beam. However, normal practice is aligning the laser beam (by adjusting the laser head) to match the optics path. In any measurement made with the laser measurement system, the laser head must be aligned to the optic's or the machine's travel path. Section 5.5.2. provides the steps and information required to adjust the laser head to the travel path of the optics.

6.5. Perpendicular Axis Measurements

If a measurement axis is perpendicular to the laser beam, the user should mount the interferometer in line with the laser and at the end of the axis being measured. Refer to Figure 6-5.

6.6. Effects on Accuracy

For effects on accuracy and sources of error, refer to Section 5.7 in Chapter: 5 Linear Displacement and Velocity Measurements.

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CHAPTER 7: SYSTEM MAINTENANCE

In This Section:

7.1. Introduction

This chapter provides information for maintaining the components of the LZR2000 interferometer system.

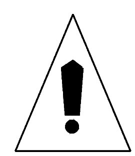
7.2. Storing the Components of the LZR2000 System

The LZR2000 system consists of precision components. These components are designed to withstand the rigors of daily use for many years. However, if the system is used infrequently, return the components to their original packaging for storage. This prevents moisture, dust and other foreign materials from collecting on the system components. Always store the boxes in a temperature-controlled environment that is free of excessive vibrations and moisture.

7.3. Cleaning the Laser Head

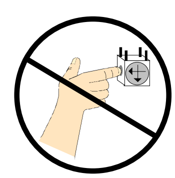
The LZR2000 laser head has a sturdy metal enclosure to add stability and protect the internal components. If the metal enclosure becomes dirty, it can be cleaned with a mild detergent using a soft, damp cloth. Be careful not to touch either of the apertures on the laser head and be careful not to get any moisture near the electrical connectors or the apertures.

> The cleaning procedure for the laser head is only for the external surfaces. In addition, the laser head should never be opened for cleaning or servicing. The internal portion of the laser head contains high voltages that could result in electrocution. There are no user-serviceable components inside the laser head. For information on servicing, call the Technical Support Department at Aerotech, Inc.



WARNING

7.4. Cleaning the Optics



The optical components of the LZR2000 system are precision devices. Never touch the surface of any optical device or the apertures of the laser head. When optical devices are touched, residue can remain on the optical surfaces, collect other contaminants and ultimately impede the performance of the system. If the optical components have become dirty, they may be rinsed using pure methanol. A squirt bottle can be used to spray a light stream of methanol over the optical component. Do not wipe or rub anything over the optical apertures. Simply spray the component lightly with pure methanol and let it air dry. Note that optical components should be cleaned only when it is absolutely necessary (e.g., if the surfaces have been touched). It is best to simply avoid touching any of the glass surfaces of the optical components. Other acceptable cleaning fluids include ethanol, de-ionized water and acetone.

7.5. Calibration

The LZR2000 laser head is calibrated at the factory before it is shipped. Recalibration of the laser head is unnecessary with normal operation. However, the optional Environmental Compensator (LZR1100) may need to be recalibrated periodically, even though it is initially calibrated at the factory. Aerotech recommends that the LZR1100 be calibrated approximately once per year or as needed. Call the Technical Support Department for details.

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CHAPTER 8: TECHNICAL DETAILS

In This Section:

8.1. Introduction

This chapter provides technical details for all of the components of the LZR2000 system. Each of the remaining sections of this chapter discusses the technical details for separate parts of the LZR2000 system (e.g., the laser head, optics and accessories, environment and material compensation, and miscellaneous specifications). These details include signals and pinouts for electrical connections, general specifications (such as power requirements, temperature operating ranges, accuracy values, weight, etc.), dimensions, switch settings and jumper settings.

8.2. The LZR2000 Laser Head

This section describes technical details associated with the LZR2000 laser head.

8.2.1. Electrical Connections of the Laser Head

The LZR2000 laser head has three electrical connectors: a standard AC power connector, a round 8-pin A-quad-B SIN/COS output connector, and a 9-pin D-type A-quad-B line driver output connector. These connectors are illustrated in Figure 8-1.

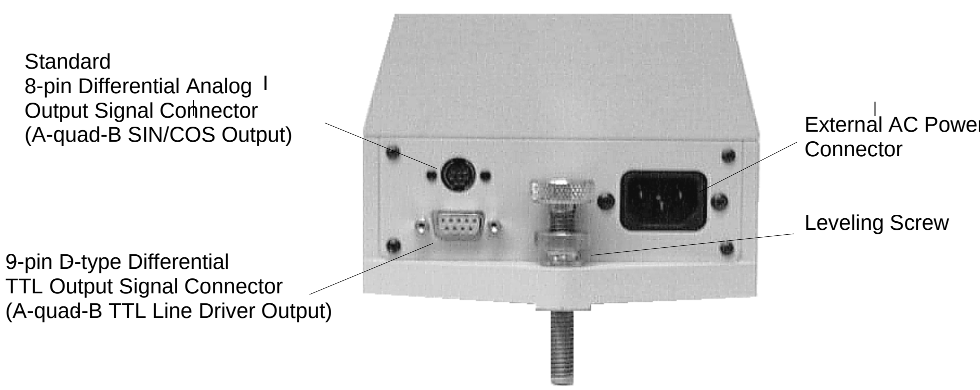


Figure 8-1. Rear View of the LZR2000 Laser Head

The signals for the 8-pin and 9-pin connectors are listed in Table 8-1 and Table 8-2.

Table 8-1. Pinouts for the 8-pin DIN Output Connector of the Laser Head

Pin #	Pin Name	Description
1	SIN A	A-quad-B SIN output signal
2	$\overline{\text{SIN A}}$	A-quad-B SIN output signal (low active)
3	COS A	A-quad-B COS output signal
4	$\overline{\text{COS A}}$	A-quad-B COS output signal (low active)
5	GND	Ground
6	VDC	+5 Volts DC
7	$\overline{\text{Laser On}}$	Signal that corresponds to the “Laser On” LED
8	$\overline{\text{Stable}}$	Signal that corresponds to the “Laser Ready” LED

Table 8-2. Pinouts for the 9-pin D-type Output Connector of the Laser Head

Pin #	Pin Name	Description
1	SIN	A-quad-B line driver output signals
2	$\overline{\text{SIN}}$	A-quad-B line driver output signals (low active)
3	COS	A-quad-B line driver output signals
4	$\overline{\text{COS}}$	A-quad-B line driver output signals (low active)
5	GND	Ground
6	VDC	+5 VDC Output Signal
7	$\overline{\text{Laser On}}$	Signal that corresponds to the “Laser On” LED
8	$\overline{\text{Stable}}$	Signal that corresponds to the “Laser Ready” LED
9	GND	Ground

8.2.2. General Specifications of the Laser Head

General specifications for the LZR2000 laser head are listed in Table 8-3.

8.2.3. Dimensions of the Laser Head

Physical dimensions of the LZR2000 laser head are illustrated in Figure 8-2.

Table 8-3. General Specifications for the LZR2000 Laser Head

Specification	Description
Laser type	Helium-Neon (HeNe), single frequency
Maximum output power	1 mW
Warm-up time	15 minutes, maximum
Vacuum wavelength (λ)	632.9907 nm
Wavelength accuracy	± 0.1 ppm
Wavelength stability	± 0.002 ppm / hour, ± 0.02 ppm / month
Beam diameter	5 mm
Beam centerline spacing	11 mm
Safety classification	Class II
Power requirements	50 watts at 100-240 VAC
Output signals	λ/2 A-quad-B complimentary line driver output, λ/2 A-quad-B complimentary sinusoidal output (0 to ±1.5 V peak) Laser on and laser ready (TTL)
Dimensions (LxHxW)	15.38” x 5.50” x 4.04” (390,6 mm x 139,7 mm x 102,4 mm)
Weight	12 lb (5,5 kg)
Operating Temperature	15 - 40°C
Relative Humidity	0-90% Non condensing
Shock (IEC 68.2.27)	30G, 11 msec

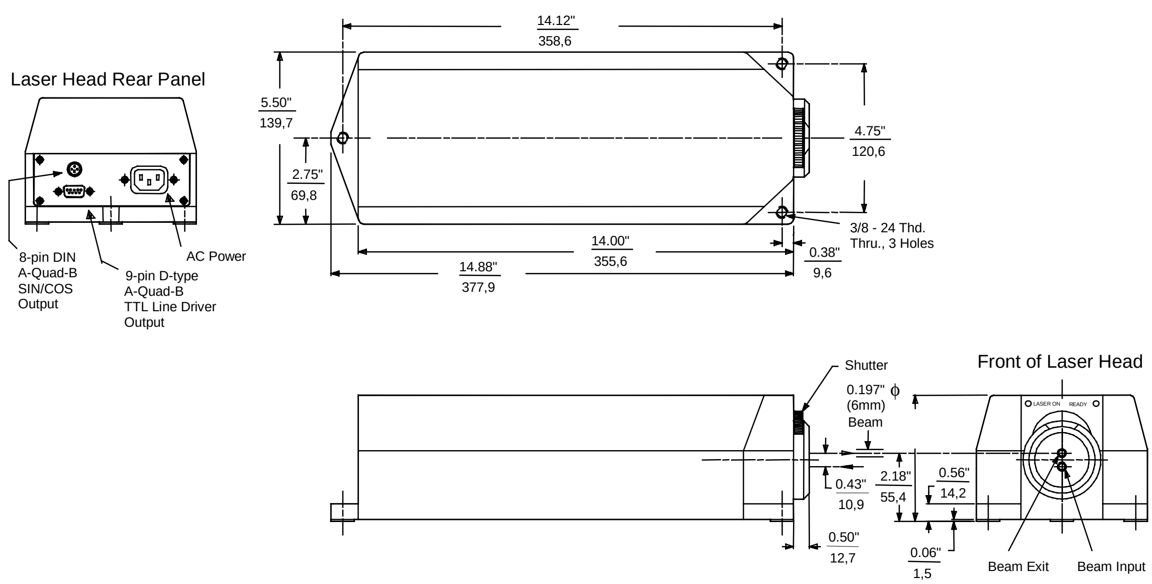


Figure 8-2. Dimensions of the LZR2000 Laser Head

8.3. Optics and Optical Accessories

This section summarizes technical details that relate to the optics and optical accessories of the LZR2000 system. Technical details of the optics of the LZR2000 system are illustrated in Figure 8-3 and Figure 8-4.

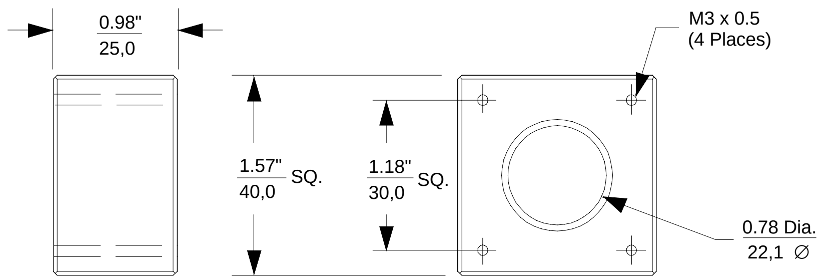


Figure 8-3. Dimensions of the LZR2400 Optical Retroreflector

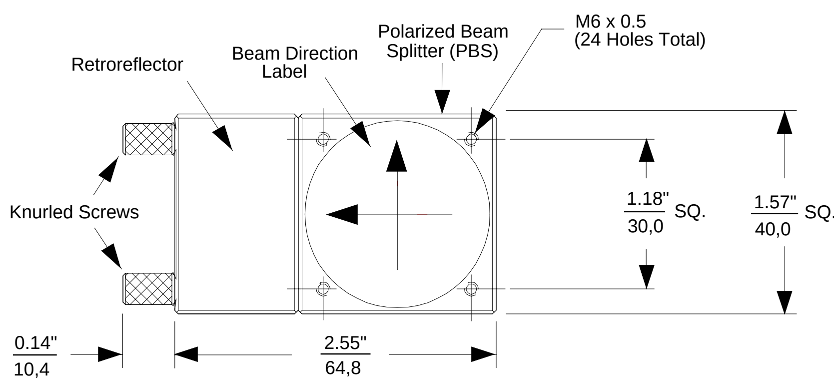
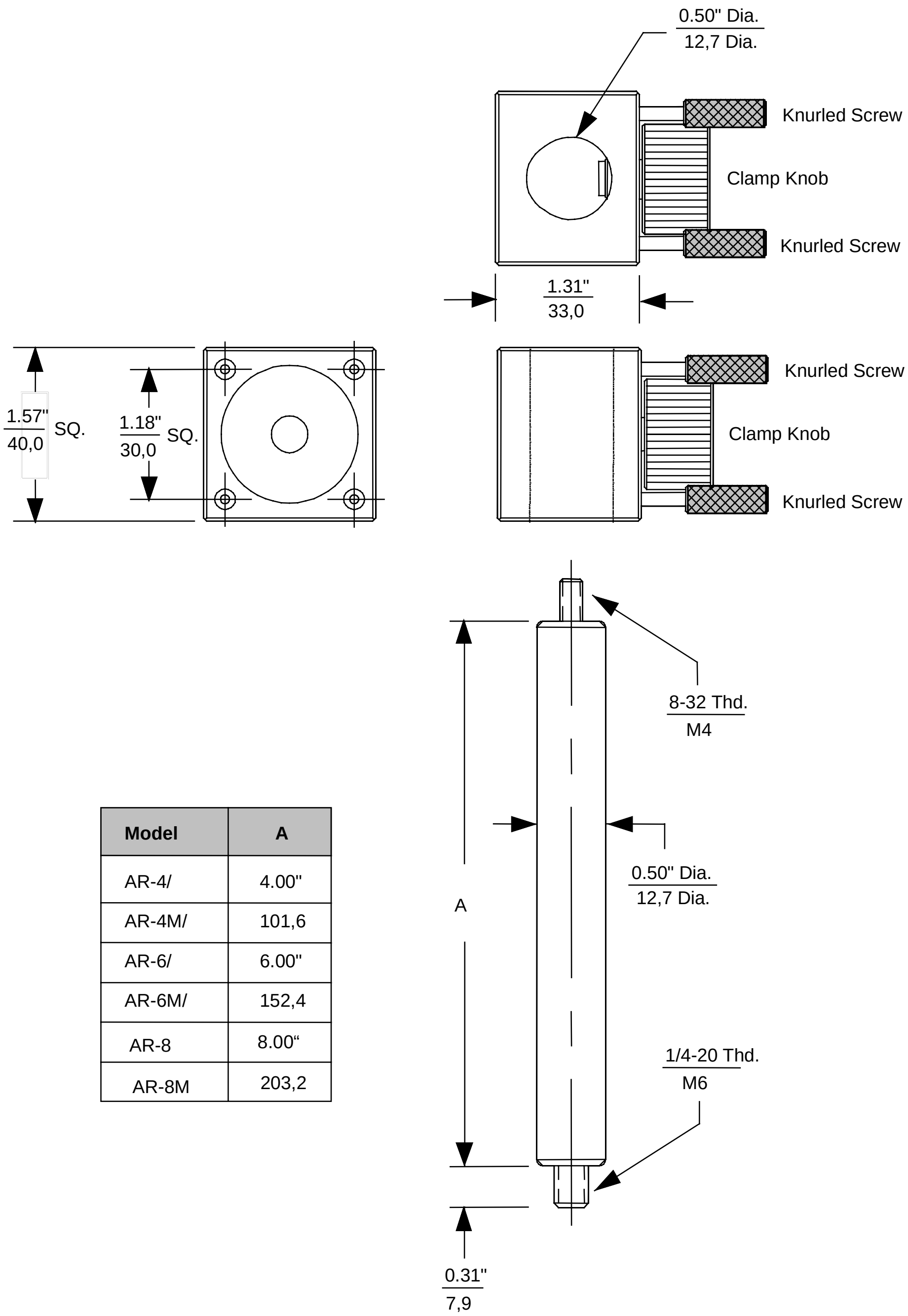


Figure 8-4. Dimensions of the LZR2300 PBS/Retro Combination

Posts and post-mount height adjusters (LZR1001) are optical accessories that can be used to secure all the optics to the appropriate surfaces. The dimensions of these accessories are illustrated in Figure 8-5.



Model	A
AR-4/	4.00"
AR-4M/	101,6
AR-6/	6.00"
AR-6M/	152,4
AR-8	8.00“
AR-8M	203,2

Figure 8-5. Dimensions of the Post-Mount Height Adjuster and Posts

The base (LZR1002) is an optical accessory that can be used to provide a means of support for the post-mount height adjuster. This configuration offers additional flexibility when setting up the optics. The dimensions for base are shown in Figure 8-6.

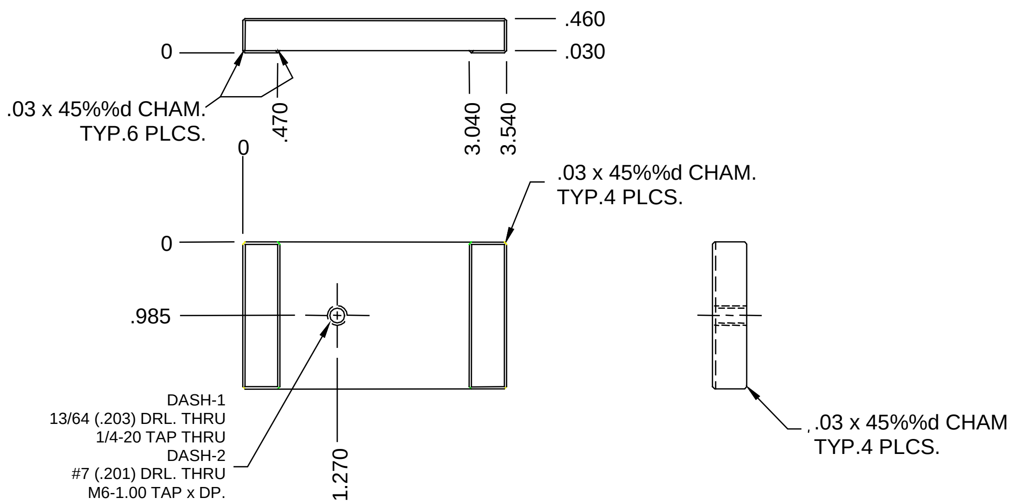


Figure 8-6. Dimensions of the LZR1002 Base

The quarter wave plate (LZR2710) is used for plane/flat mirror measurements. The dimensions for the quarter wave plate are shown in Figure 8-7.

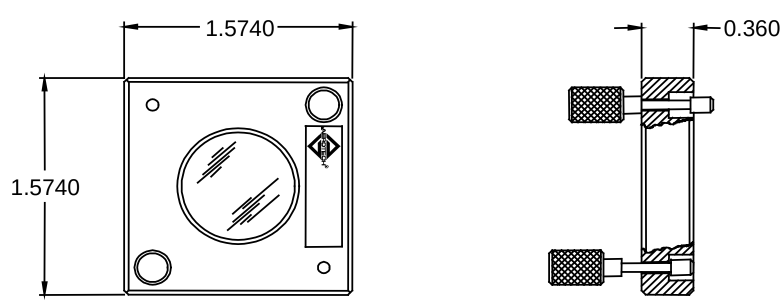


Figure 8-7. Dimensions of the LZR2710 Quarter Wave Plate

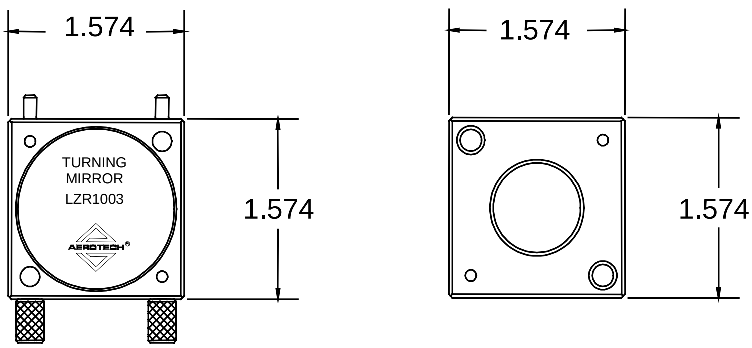


Figure 8-8. Dimensions of the Turning Mirror (Cube) LZR1003

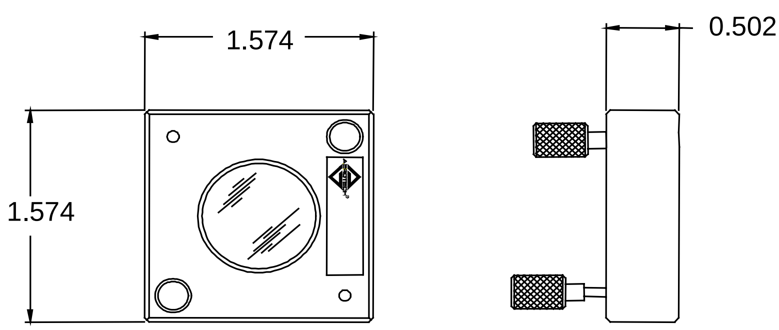


Figure 8-9. Dimensions of the Mirror (LZR1004, LZR1005 & LZR2720)

8.4. Environmental and Material Expansion Compensation

This section contains technical details about the optional environmental compensator (LZR1100). This package includes sensors to measure ambient air temperature and pressure. Additional material temperature sensors (LZR1010) may be connected to the unit to provide thermal material expansion compensation, in addition to a remote ambient temperature sensor (LZR1020).

Technical details for the LZR1100 environmental compensator are provided in Table 8-4. Table 8-5 contains the technical details of the material temperature sensors. Table 8-6 contains the technical details of the remote ambient temperature sensor. The LZR1100 connects directly to the Misc. I/O connector of the DR300 / DR500 / DR600 / DR800 chassis.

See the online help documentation for more information on using the LZR1100.

Table 8-4. Environmental Compensation Specifics of the LZR1100

Specification	Description
Measurement range	Temperature: 15 °C to 40 °C Pressure: 550-790 mm of Hg
Measurement accuracy	For the range 19 °C to 21 °C: 1.5 ppm For the range 15 °C to 25 °C: 1.7 ppm
Time constants	Temperature: 10 sec, typical Pressure: 1 sec, typical
Maximum update rate	0.5 Hz
Wavelength compensation	Manual (Keyboard entry) or Automatic (with air sensor); Temperature and pressure monitored; Humidity setting manually entered; Wavelength computed
Signal cable	25-pin D-type DR500 Misc. I/O connector
Optional material temperature sensor	Up to four (4) material temperature sensors and (1) remote ambient temperature sensor can connect to the LZR1100 air sensor

Table 8-5. Specifics of the Material Temperature Sensors (LZR1010)

Specification	Description
Temperature range	0-50°C
Measurement Accuracy	0.4°C
Time Constant	10 sec
Temperature compensation	• Manual via keyboard entry • Automatic with material temperature sensors; temperature monitored

Table 8-6. Specifics of the Remote Ambient Temperature Sensor (LZR1020)

Specification	Description
Temperature range	Temperature: 15 °C to 40 °C
Measurement Accuracy	For the range 19 °C to 21 °C: 1.5 ppm For the range 15 °C to 25 °C: 1.7 ppm
Time Constant	Temperature: 10 sec, typical
Temperature compensation	Manual via keyboard entry Automatic with ambient temperature sensors

The LZR1100 environmental compensator, LZR1010 material temperature sensor, and the LZR1020 remote ambient temperature sensor are illustrated in Figure 8-10. The dimensions for the material temperature sensor and the environmental compensator are illustrated in Figure 8-11, Figure 8-12, and Figure 8-13.

Figure 8-10. LZR1100 Air Sensor, LZR1010 Material Temperature Sensor and LZR1020 Remote Ambient Temperature Sensor

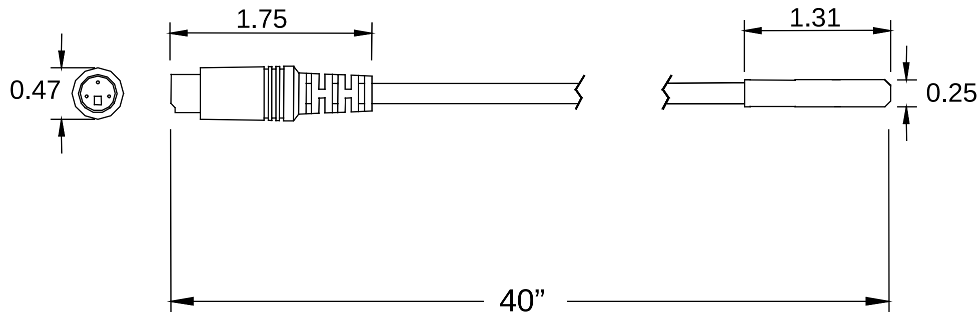


Figure 8-11. Dimensions of the LZR1010 Material Temperature Sensor

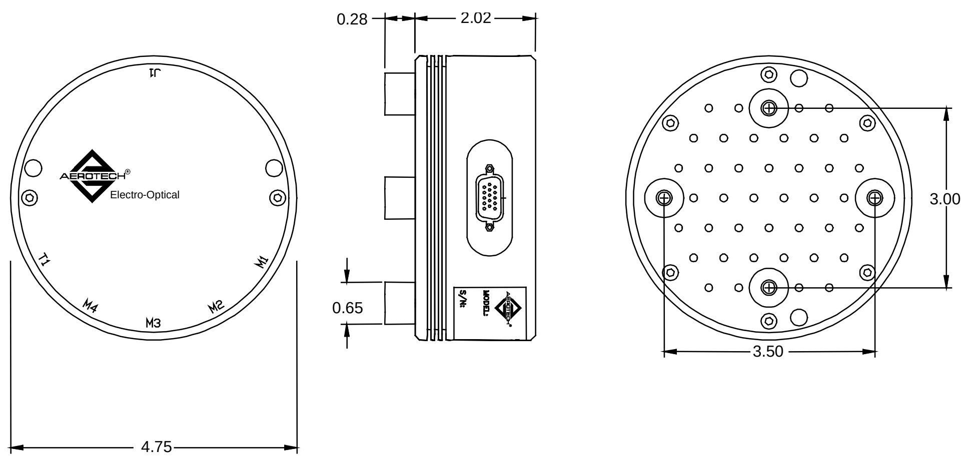


Figure 8-12. Dimensions of the LZR1100 Environmental Compensator

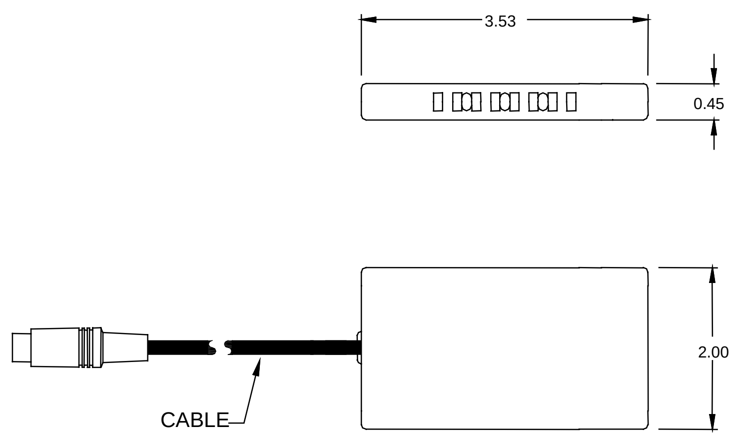


Figure 8-13. Dimensions of the LZR1020 Remote Ambient Temperature Sensor

8.5. Miscellaneous Specifications

This section contains miscellaneous technical specifications not found in the previous sections.

8.5.1. Resolution and Velocity for Linear Displacement

Technical details about the resolution and velocity for linear displacement are listed in Table 8-7.

Table 8-7. Resolution and Velocity Details

Accuracy			
Temp. Range	**Uncompensated**	**Compensated**	**Vacuum**
20°±1°C	±10 ppm	±1.5 ppm	±0.1 ppm
20°±5°C	±14 ppm	±1.7 ppm	±0.1 ppm
Measurement Range (Axial Separation)			
10m (33 feet)			

8.5.2. Plane/Flat Mirror Measurement Specifications

Technical operating specifications for plane/flat mirror measurements are listed in Table 8-8.

Table 8-8. Plane/Flat Mirror Operating Specifications

Accuracy			
Temp. Range	**Uncompensated**	**Compensated**	**Vacuum**
20°±1°C	±10 ppm	±1.5 ppm	±0.1 ppm
20°±5°C	±14 ppm	±1.7 ppm	±0.1 ppm
Measurement Range (Axial Separation)			
5m (16.5 feet)			

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CHAPTER 9: TROUBLESHOOTING

In This Section:

9.1. Introduction

This chapter assists in diagnosing problems that may arise during the commissioning or operation of your LZR2000 system.

9.2. Setup and Alignment

Problems that may arise during system setup and optical alignment are listed in Table 9-1. Possible causes and solutions are also given.

Table 9-1. Setup and Alignment Problems

Problem	Cause/Solution
No beam appears and the "Laser On" LED is not lit...	No power to the laser head.
No source beam appears, but the "Laser ON" LED is lit"...	The shutter on the laser head may be in the closed position or the laser head is still warming up.
A weak beam appears and the "Laser On" LED blinks on and off... after 15 minutes of warm-up	Possible damage to laser tube. Call Aerotech.
No return beam appears...	Optical components are not properly aligned (beam may not be centered on optical components). Optical components are not properly situated (check directions of arrows on the PBS). Retroreflector may be rotated 90 degrees (be sure that beam strikes the center of a retroreflector's "triangle" and not on an edge). The shutter on the laser head may be in the closed position.

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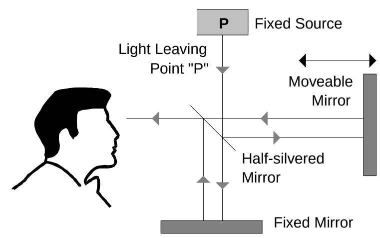
APPENDIX A: GLOSSARY OF TERMS

In This Section:
- Terms Used In This Manual
- Abbreviations Used In This Manual
- Definitions

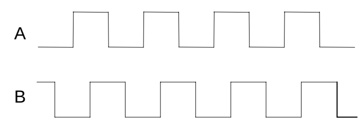
This appendix contains definitions of terms that are used throughout this manual.

A. A. Michelson interferometer - The A. A. Michelson interferometer was originally built in 1881 by Michelson (1852-1931), America's first Nobel prize winner in Science. This model used a half-silvered mirror (rather than the modern day polarized beam splitter) that transmitted half of the light (the reference beam) and reflected the other half (the measurement beam). The measurement and reference beams are combined to cause interference fringes when the measurement mirror (i.e., the modern day retroreflector) is moved. Very accurate distances can be measured by counting the interference fringes during this movement. The number of interference fringes counted is proportional to the distance moved. The LZR2000 laser interferometer uses this model for its distance calculations.



A.A. Michelson Interferometer

A-quad-B output - An A-quad-B output is a two-signal output in which the two signals are displaced 90 degrees with respect to each other. An A-quad-B output signal is a common interface to motion controllers (e.g., the UNIDEX 600). Both line drive and SIN/COS output signals are available on the LZR2000 laser head.



A-quad-B Output

Abbé error - Abbé error (named after optical designer Ernst Abbé) is a linear error (e.g., an incorrect distance measurement) that is caused by an angular error (e.g., a deviation in the motion surface). Abbé error is introduced into the LZR2000 System when the motion surface (e.g., the stage) has a yaw curvature, for example. As a result of this curvature, an angular error will exist between the reported position of the stage (from an encoder, for example) and the measured distance from the interferometer.

The effects of Abbé error can be minimized by reducing the angular error in the motion surface (i.e., by ensuring flatness, straightness, etc.). This can be accomplished by using the numerous other available optical kits. Abbé error could be virtually eliminated by mounting an LVDT (or similar touch probe) directly to the measurement retroreflector. Other ways to minimize the effects of Abbé error include: (1) using precision mechanical components for motion, (2) using mechanical components with air bearings, (3) using precision ground mounting surfaces (granite tables, etc.), and (4) keeping the measurement device above the base of the mounting surface over the entire range of motion (i.e., do not let the measurement device extend over the base of the mounting surface).

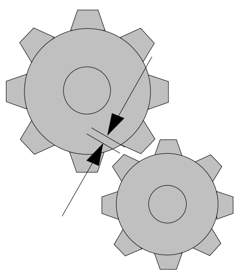
absolute pressure - Absolute pressure is the ambient pressure used by the LZR2000 system for all environmental compensation calculations. If barometric pressure (the absolute pressure corrected to sea level) is available, then an approximate absolute pressure can be determined by decreasing the barometric pressure by 1 inch of Hg for every 1000 feet of altitude above sea level.

accuracy - Accuracy is the difference between an expected value and an actual value. Accuracy may also be represented as the maximum amount of deviation from the actual value of a measurement in parts per million (ppm).

amplifier - An amplifier is a hardware device having an output that is larger than the input signal.

axis - An axis is a direction along which movement occurs.

axis calibration - Axis calibration is the process by which the actual position of an axis is adjusted to match the desired position of the axis.

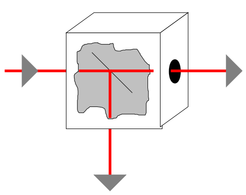


backlash in gears

backlash - Backlash is lost motion that occurs after a direction change.

barometric pressure - *See* absolute pressure.

base address - A base address is a number that represents the memory location in the computer where input/output (I/O) information can be stored. All devices (e.g., the UNIDEX 600 card, network cards, tape backup cards, etc.) within a computer must have unique I/O base addresses. Base addresses of PC boards may be set through hardware (i.e., jumpers and/or switches), software (i.e., parameters) or a combination of both hardware and software.



beam splitter

beam splitter - A beam splitter is a precision optical device that allows a portion of a laser beam to be transmitted while the other portion is reflected. Beam splitters divide a laser beam into two beams (that are usually perpendicular to each other). Beam splitters are available with different transmission/reflection percentages (e.g., 50% transmit/50% reflect, 30% transmit/70% reflect, etc.).

breadboard (optical) - In optics and laser interferometry, a breadboard refers to a precision table top that contains aligned, pre-drilled holes for securing optical (and other system) components.

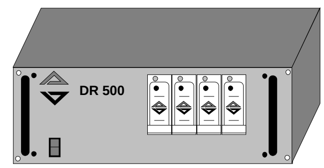
closed-loop system - A closed-loop system is a type of drive system that uses sensors or transducers for direct feedback of position and/or velocity. An example of a closed-loop system is a stage which receives a position signal from an encoder. For applications that require extreme accuracy, a laser interferometer can be used to provide the feedback. Contrast with open-loop system.

cosine (COS) error - Depending on the system configuration, the mechanical axis (i.e., the axis of motion) and the travel axis of the laser beam should be either parallel or perpendicular to each other. If these two axes are misaligned, then the two distances would be slightly different. This difference represents an error that is a function of the angle of misalignment between the two axes (specifically, the cosine of this angle) and the path of the laser beam. For this reason, this type of error is called Cosine error.

To reduce the effects of cosine error, the motion axis of the retroreflector must be parallel (or perpendicular depending on the configuration) to the path of the laser beam. If these axes are misaligned, then the distance being measured by the LZR2000 System will be the distance offset by the angle θ. Careful beam angle pitch and yaw adjustments may be necessary to maximize accuracy and minimize the effects of cosine error.

dead path - Dead path is the distance between the fixed PBS and the measurement retroreflector in the interferometer system when the system is zeroed. This definition assumes that the PBS/retro components are connected. If the PBS/retro combination is separated, the actual dead path becomes the difference between the measurement dead path distance (the distance between the fixed PBS and the measurement retroreflector) and the reference dead path distance (the distance between the fixed PBS and the fixed reference retroreflector).

dead path error - Dead path error is an inaccuracy in the interferometer measurement due to environmental changes of the air (e.g., air temperature, air pressure and humidity) over the distance of the dead path. The effects of dead path error can be minimized by reducing the dead path. If the PBS/retro is as close as possible to the measurement retroreflector and measurement dead path error is still a problem, consider operating the interferometer system (or at least the dead path portion) within a vacuum. If this is impossible or impractical, it is also possible to offset the effects of dead path error by introducing an equal error into the reference path. This can be done by separating the PBS/retro combination a distance equal to the dead path of the measurement beam. Dead path is defined as the difference in these two distances. If they are the same, then the dead path error will be zero (or negligible).

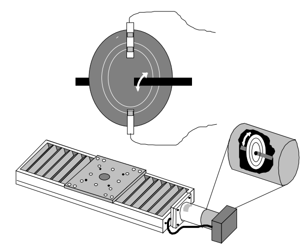


DR500 Drive Rack

DR500 Chassis/Drive Rack - The DR500 Chassis (or Drive Rack) is a housing for the axis amplifiers (for microstepping, DC brush and brushless drivers) and the driver power supply. The DR500 is available in rack mount, panel mount and desktop packaging.

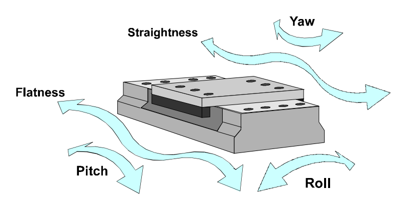
dynamic link library - A dynamic link library is a set of program routines that are available to applications at run time.

encoder - An encoder is a linear or rotary device that produces a signal based on change in position.



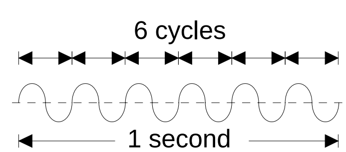
stage with rotary encoder

flatness - Flatness is the condition of a surface (such as a stage) such that all points of the surface exist in a single plane. Flatness of travel is the deviation between the theoretical and actual axes of travel measured in the horizontal plane. Flatness of travel deviations are primarily a function of pitch and roll errors.



floating point number format - Floating point number format is a method of representing numbers without defining a fixed number of decimal places. Two common forms of floating point number format are fixed-style format (e.g., 12.345, 0.000001, -2, etc.) and scientific notation (e.g., 12.3E4, -1.2E-3, etc.). In the scientific notation method, the number that follows the "E" represents a power of 10. For example, 12.3E4 means 12.3×10^4 or 123,000.

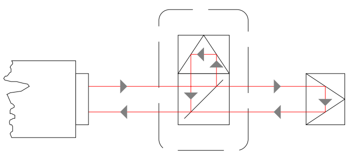
frequency - Frequency is the number of cycles of a wave (e.g., light) that occur within a unit time. The standard measurement for frequency is Hertz (Hz) which represents one cycle per second. For very large frequencies, it is common to use prefixes such as K for 1,000 (10 KHz=10,000 cycles per second) or M for 1,000,000 (50 MHz=50,000,000 cycles per second). Frequency (f) of an electromagnetic (light) wave can be represented using the equation $f = v/\lambda$, where v is the velocity of light (approximately 300,000,000 m/sec [in a vacuum]) and λ is the wavelength.



frequency

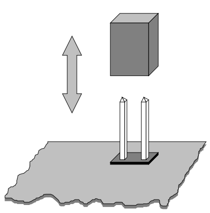
frequency shift - Frequency shift is a phenomenon that occurs in Doppler interferometry when a single-frequency wave is split (into a reference beam and a measurement beam) and then reunited to cause interference. The interference occurs as the length of the measurement beam changes (due to motion).

hexadecimal number format - Hexadecimal number format is a method of representing large numbers using base 16 rather than the standard base 10. In base 16 or hexadecimal number format (often abbreviated "hex"), the number positions represent powers of 16 (rather than powers of 10 in decimal). The decimal number positions (1's, 10's, 100's, 1,000's, 10,000's, etc.) are replaced with hexadecimal number positions (1's, 16's, 256's, 4096's, etc.). Also, while the individual numerals for the decimal system are 0-9, the numerals for the hexadecimal number system (which requires 16 unique "numerals") are 0-9 then A-F (where $A_{16}=10_{10}$, $B_{16}=11_{10}$, $C_{16}=12_{10}$, $D_{16}=13_{10}$, $E_{16}=14_{10}$, and $F_{16}=15_{10}$). For simplicity in this manual, hexadecimal numbers are written with a preceding "0x" rather than using the subscript 16. For example, the hexadecimal number 12A5 is written 0x12A5. Numbers without the preceding "0x" are assumed to be decimal unless otherwise indicated.



interferometer

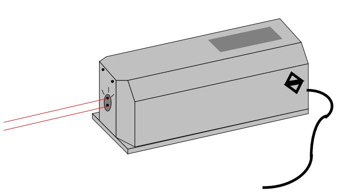
interferometer - An interferometer refers to a complete system (including all of the optics and the laser head) used to make precise measurements. The term interferometer may also refer to an optical device that uses light interference phenomena for precise determinations of wavelengths and small linear displacements. The LZR2300 (linear) interferometer consists of a polarized beam splitter and a retroreflector that are connected (PBS/retro). As a laser beam hits the internal mirrored surface of the beam splitter, a portion is reflected from the beam splitter to a retroreflector (this portion of the wave is called the reference beam, since the distance of its path is fixed and can be used as a reference) and another portion is transmitted through the beam splitter (this portion of the beam is called the measurement beam, since the distance of its pathway will vary and will represent the distance to be measured). Both waves are reflected back to the mirror in the beam splitter where they interfere (due to movement of the measurement retroreflector). The resulting interference can be interpreted to determine the precise distance that the measurement retroreflector has traveled.



jumper

jumpers - Jumpers are hardware *ties* that you manually position to configure the hardware platform. A small "block" is either installed (placed over a pair of pins) or it is removed, providing a two-state input (e.g., enable/disable, on/off, 0/1, etc.). Jumpers are found on PC boards and are typically used to configure features (e.g., addresses, interrupts, etc.).

laser - The term laser is an acronym for Light Amplification from the Stimulated Emission of Radiation and refers to a device that produces such light. The LZR2000 laser head contains a single-frequency, class II helium (He) and neon (Ne) laser. This laser provides the single focused light beam that is the key element of the interferometer system.

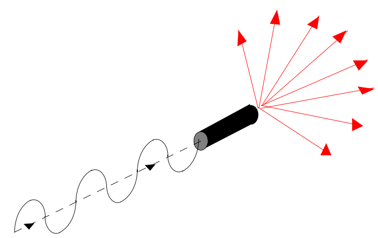


LZR2000 laser head

laser head - A laser head is an enclosure that houses and protects a laser and its associated components and circuitry. The LZR2000 laser head contains electrical connections for power and interference output signals. Laser beam exit and detection apertures, an aperture shutter and diagnostic LEDs are also found on the laser head.

laser interferometry -Laser interferometry is an extremely accurate method of distance measurement (as well as flatness, straightness, squareness, parallelness, and others). It involves the use of a laser, an interferometer (a precision optical device used to split the laser beam and create interference fringes) and additional optics. The LZR2000 performs single-axis linear displacement measurements and uses single-frequency Michelson laser interferometry. This method of interferometry counts interference fringes (that occur as the target moves along its axis from a known starting position to a destination position) and accurately calculates the precise distance traversed.

least squares - A procedure in which the basic problem is to pass a curve through a set of points, representing experimental data, in such a way that the curve shows as well as possible the relationship between the two quantities plotted. Using one's knowledge of the functions that have been found useful in fitting various experimental curves, one selects a suitable function and tries to determine the parameters left unspecified. At this point there are certain techniques that have been worked out to choose the optimum value of the parameters. One of the most general methods used for this purpose is least squares. In this method one chooses the parameters in such a way to minimize the sum representing the best line through the data.



LED

LED - LED is an acronym for light-emitting diode. An LED is a semiconductor diode that converts electrical energy into visible electromagnetic radiation. Several LEDs are found on the LZR2000 laser head and are used for diagnostic purposes.

LZR1001 - The LZR1001 is a post-mounted height adjuster that connects an optical component (e.g., an LZR2400 linear reflector) to a mounting post (e.g., AR-4/, AR-4M/, AR-6/, or AR-6M/).

LZR1002 - The LZR1002 is the base plate that provides a means of support for the post-mounted height adjusters.

LZR1003 - The LZR1003 is a turning mirror (cube) used applications that require the laser beam to be reflected or directed at an angle of 90 degrees.

LZR1004 - The LZR1004 is a mirror used with applications requiring the laser beam reflected at an angle that is perpendicular to the mirror.

LZR1005 - The LZR1005 is a mirror used applications that require the laser beam to be reflected or directed at an angle of 90 degrees.

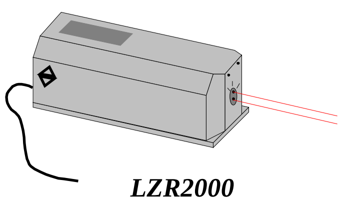
LZR1010

LZR1010 - The LZR1010 is an optional material temperature sensor (with cable) that is used with the LZR1100 (the environmental compensation package). Up to four material temperature sensors can be used with the LZR1100 to improve accuracy by compensating for measurement errors due to thermal expansion of mounting surfaces. If more than one material temperature sensor is used, the controller's software averages the temperatures into a single temperature for compensation purposes.

LZR1020 - The LZR1020 is an optional remote ambient sensor (with cable) that is used with the LZR1100 (the environmental compensation package). Up to four remote ambient sensors can be used with the LZR1100 to improve accuracy by compensating for measurement errors due to temperature. If more than one remote ambient temperature sensor is used, the controller's software averages the temperatures into a single temperature for compensation purposes.

LZR1100

LZR1100 - The LZR1100 is the option environmental compensation package. This kit contains the electronics, air sensor and 10-foot cable which connects to the Misc. I/O connector of the DR500. With this optional package, the LZR2000 system can automatically compensate for measurement errors due to environmental fluctuations in temperature and pressure. A manual humidity input is also available for additional environmental compensation.



LZR2000

LZR2000 - The LZR2000 is the single-frequency, helium-neon laser head component of the LZR2000 system. The laser head is an enclosure that houses and protects a laser and its associated components and circuitry. The LZR2000 laser head contains electrical connections for power and interference output signals. Laser beam exit and detection apertures, an aperture shutter and diagnostic LEDs are also found on the laser head.

LZR2300

LZR2300 - The LZR2300 is the combination PBS (polarized beam splitter) and retroreflector. This optical component of the LZR2000 system is a precision optical device that is placed between the laser head and the measurement retroreflector. The PBS\retro splits the incident beam from the laser head into two beams. One beam is reflected from the mirrored surface of the PBS, and the other beam is transmitted through the mirrored surface of the PBS. Of these two beams, one goes to a fixed retroreflector (creating the reference beam) and one goes to a moveable retroreflector (creating the measurement beam).

LZR2400

LZR2400 - The LZR2400 is the linear reflector optical component of the LZR2000 system. A retroreflector is a precision optical device that reflects light from a laser such that the reflected rays are parallel to the incident rays. In a linear interferometer system, one retroreflector moves along the measurement axis (changing the distance of the measurement beam) and the other is part of the fixed-position interferometer.

LZR2410 - The LZR2410 is an alignment target used for aligning the optics to the laser beam.

LZR2700 - The LZR2700 is the plane mirror optical kit typically used for X-Y stage applications where movement perpendicular to the laser axis is limited in traditional retroreflector (linear) measurement optics.

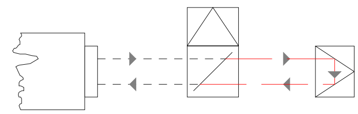
LZR2710 - The LZR2710 is the quarter wave plate.

LZR2720 - The LZR2720 is an optical plane mirror used with the LZR2700 plane/flat mirror optical kit.

LZR2900- The LZR2900 is the linear optical kit that contains the LZR2300 linear retroreflector and the LZR2400 linear reflector. It is an optic that is used when the original linear optics were not purchased.

LZR2000 Laser Feedback System - The LZR2000 is a Laser Feedback System that includes a laser head, optics, and cables. The LZR2000 system is used for single-axis linear displacement measurements.

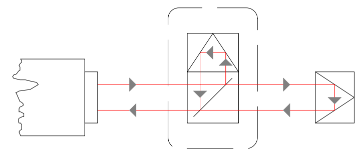
measurement beam - Measurement beam refers to one of two laser beams used in the LZR2000 Laser Feedback System. The main laser beam (from the laser head) is split into the measurement beam and the reference beam at the beam splitter. The reference beam travels to a fixed retroreflector, is reflected, and returns to the beam splitter. The measurement beam travels to a retroreflector that is attached to the moving measurement object and is reflected back to the beam splitter where it is reunited with the fixed reference beam to create an interference pattern. This pattern is interpreted to determine the precise distance that was traversed by the measurement beam.



measurement beam

open-loop system - An open-loop system is a type of drive system that does not employ feedback sensors or transducers to monitor position or velocity. Most stepper motor applications are open loop (that is, they have no feedback). The commanded position is the assumed motor position. Contrast with closed loop system.

PBS/retro - PBS/retro is an abbreviation for two combined optical components: the polarized beam splitter (PBS) and a retroreflector (retro). The PBS\retro is a precision optical device that is placed between the laser head and the measurement retroreflector. The PBS\retro splits the incident beam from the laser head into two beams. One beam is reflected from the mirrored surface of the PBS, and the other beam is transmitted through the mirrored surface of the PBS. Of these two beams, one goes to a fixed retroreflector (creating the reference beam) and one goes to a moveable retroreflector (creating the measurement beam).



PBS/retro

photo diode - A photo diode is an electronic component that acts as a one-way "valve", and converts light (from a laser, for example) into electrical signals. Photo diodes are used in the detector circuitry of the LZR2000 laser head.

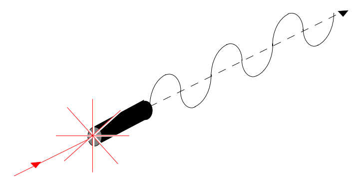
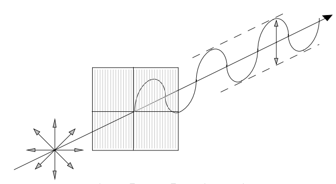


photo diode

pitch - Pitch is a rotation about the horizontal axis and perpendicular to the axis of travel. Pitch is an angular movement (or error) that affects flatness of travel and positioning accuracy (of a stage, for example).

polarization - Polarization is the process by which one or more transverse waves (e.g., light) become aligned, such that only vector components that lie in the plane of wave propagation remain.

polarized beam splitter - A polarized beam splitter (or PBS) is a precision optical device that polarizes/reflects a portion of a laser beam and polarizes/transmits another portion.

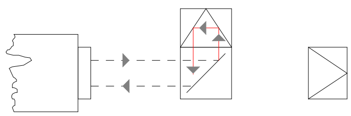


vertical polarization

quadrature - Quadrature is the state of two signals that are displaced 90 degrees with respect to each other. In most rotary incremental optical encoders, light (from an LED, for example) is measured after it is passed through slits in a grating disk (which is attached to the axis being measured). Typically, two tracks on the disk have their gratings displaced 90 degrees with respect to each other (that is, the tracks are said to be in quadrature).

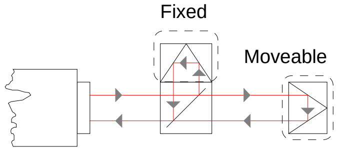
quarter wave plate - A quarter wave plate (QWP) is an optical device used in the detector portion of the laser head. The QWP is an optical plane comprised of two refractive indices. This device performs the necessary wave shifting of the returned laser beam which allows the vector components of polarized beams to come through. The QWP prepares the wave for fringe counting and output manipulation.

range - Range is a term used to specify the maximum recommended operational distance of the LZR2000 system. This linear distance is measured from the front of the laser head to the target retroreflector (at is furthest distance from the laser head). The range of the LZR2000 system is 10 meters (or 32.8 feet). The round trip of the laser beam is actually 20 meters (or 65.6 feet) for a typical linear interferometry application (10 meters out and 10 meters back).



reference beam

reference beam - Reference beam refers to one of two laser beams used in the LZR2000 Laser Feedback System. The main laser beam (from the laser head) is split into the reference beam and the measurement beam at the beam splitter. The reference beam travels to a fixed retroreflector, is reflected, and returns to the beam splitter. The measurement beam travels to a retroreflector that is attached to the moving measurement object and is reflected back to the beam splitter where it is reunited with the fixed reference beam to create an interference pattern. This pattern is interpreted to determine the precise distance that was traversed by the measurement object.

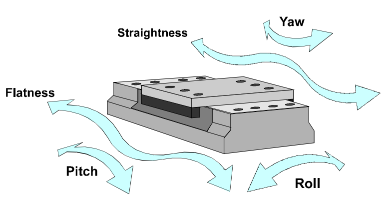


retroreflectors

retroreflector - A retroreflector is a precision optical device that reflects light from a laser such that the reflected rays are parallel to the incident rays. In a linear interferometer system, one retroreflector moves along the measurement axis (changing the distance of the measurement beam) and the other is part of the fixed-position interferometer.

roll - Roll is rotation about an axis of movement while translating about that axis. Roll is an angular movement (i.e., error) that effects straightness and flatness of travel.

SIN/COS signal - A SIN/COS signal is a uniform wave (i.e., an analog signal) that is generated from a single frequency. Contrast with TTL (digital) signal.



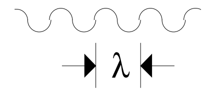
straightness - Straightness is a condition where an element of a surface or an axis is a straight line. For a positioning stage, straightness of travel is defined as the difference between the theoretical and actual axis of travel measured in the vertical plane. Straightness of travel deviations are primarily a function of yaw and roll errors.

TTL signal - A TTL (Transistor Transistor Logic) signal is a uniform square wave that is derived from two transistors. Although TTL technology is a specific design method, the term often generically to digital connections (e.g., a digital signal) in contrast with analog connections (an analog signal). Contrast with SIN/COS (analog) signal.

tuning - Tuning is the process of optimizing the operation of a servo system.

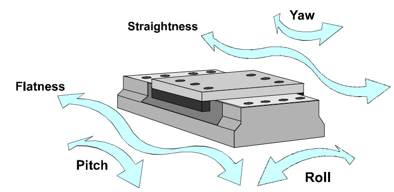
UNIDEX 600 - The UNIDEX 600 is a PC bus-based motion controller that serves as the center of a complete Aerotech motion control system. The UNIDEX 600 provides the required performance when synchronous coordination of a large number axes is a must.

wavelength (λ) - Wavelength is a distance measurement of the advance of a wave (a light wave in the case of the LZR2000) from one point to the next point of corresponding phase (i.e., one cycle). For light waves (such as those emitted from the LZR2000 laser head), the wavelength of the laser beam equals the velocity of the wave (given as a distance per unit time) divided by the frequency of the wave (given as a number of cycles per unit time).



wavelength $\lambda = v / f$

yaw - Yaw is the rotation about the vertical axis and perpendicular to the axis of travel. Yaw also refers to the angular movement (i.e., error) that effects straightness of travel and positioning accuracy. Refer to Abbé error for additional information.



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APPENDIX B: WARRANTY AND FIELD SERVICE

In This Section:
- Laser Product Warranty
- Return Products Procedure
- Returned Product Warranty Determination
- Returned Product Non-warranty Determination
- Rush Service
- On-site Warranty Repair
- On-site Non-warranty Repair

Aerotech, Inc. warrants its products to be free from defects caused by faulty materials or poor workmanship for a minimum period of one year from date of shipment from Aerotech. Aerotech's liability is limited to replacing, repairing or issuing credit, at its option, for any products which are returned by the original purchaser during the warranty period. Aerotech makes no warranty that its products are fit for the use or purpose to which they may be put by the buyer, where or not such use or purpose has been disclosed to Aerotech in specifications or drawings previously or subsequently provided, or whether or not Aerotech's products are specifically designed and/or manufactured for buyer's use or purpose. Aerotech's liability or any claim for loss or damage arising out of the sale, resale or use of any of its products shall in no event exceed the selling price of the unit.

Laser Products

Aerotech, Inc. warrants its laser products to the original purchaser for a minimum period of one year from date of shipment. This warranty covers defects in workmanship and material and is voided for all laser power supplies, plasma tubes and laser systems subject to electrical or physical abuse, tampering (such as opening the housing or removal of the serial tag) or improper operation as determined by Aerotech. This warranty is also voided for failure to comply with Aerotech's return procedures.

Return Procedure

Claims for shipment damage (evident or concealed) must be filed with the carrier by the buyer. Aerotech must be notified within (30) days of shipment of incorrect materials. No product may be returned, whether in warranty or out of warranty, without first obtaining approval from Aerotech. No credit will be given nor repairs made for products returned without such approval. Any returned product(s) must be accompanied by a return authorization number. The return authorization number may be obtained by calling an Aerotech service center. Products must be returned, prepaid, to an Aerotech service center (no C.O.D. or Collect Freight accepted). The status of any product returned later than (30) days after the issuance of a return authorization number will be subject to review.

Returned Product Warranty Determination

After Aerotech's examination, warranty or out-of-warranty status will be determined. If upon Aerotech's examination a warranted defect exists, then the product(s) will be repaired at no charge and shipped, prepaid, back to the buyer. If the buyer desires an air freight return, the product(s) will be shipped collect. Warranty repairs do not extend the original warranty period.

Returned Product Non-warranty Determination

After Aerotech's examination, the buyer shall be notified of the repair cost. At such time the buyer must issue a valid purchase order to cover the cost of the repair and freight, or authorize the product(s) to be shipped back as is, at the buyer's expense. Failure to obtain a purchase order number or approval within (30) days of notification will result in the product(s) being returned as is, at the buyer's expense. Repair work is warranted for (90) days from date of shipment. Replacement components are warranted for one year from date of shipment.

Rush Service

At times, the buyer may desire to expedite a repair. Regardless of warranty or out-of-warranty status, the buyer must issue a valid purchase order to cover the added rush service cost. Rush service is subject to Aerotech's approval.

On-site Warranty Repair

If an Aerotech product cannot be made functional by telephone assistance or by sending and having the customer install replacement parts, and cannot be returned to the Aerotech service center for repair, and if Aerotech determines the problem could be warranty-related, then the following policy applies:

Aerotech will provide an on-site field service representative in a reasonable amount of time, provided that the customer issues a valid purchase order to Aerotech covering all transportation and subsistence costs. For warranty field repairs, the customer will not be charged for the cost of labor and material. If service is rendered at times other than normal work periods, then special service rates apply.

If during the on-site repair it is determined the problem is not warranty related, then the terms and conditions stated in the following "On-Site Non-Warranty Repair" section apply.

On-site Non-warranty Repair

If any Aerotech product cannot be made functional by telephone assistance or purchased replacement parts, and cannot be returned to the Aerotech service center for repair, then the following field service policy applies:

Aerotech will provide an on-site field service representative in a reasonable amount of time, provided that the customer issues a valid purchase order to Aerotech covering all transportation and subsistence costs and the prevailing labor cost, including travel time, necessary to complete the repair.

Company Address

Aerotech, Inc.
101 Zeta Drive
Pittsburgh, PA 15238-2897
USA

Phone: (412) 963-7470
Fax: (412) 963-7459

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READER'S COMMENTS

LZR2000 and Laser Feedback System Manual
P/N EDU 169, October, 2000

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