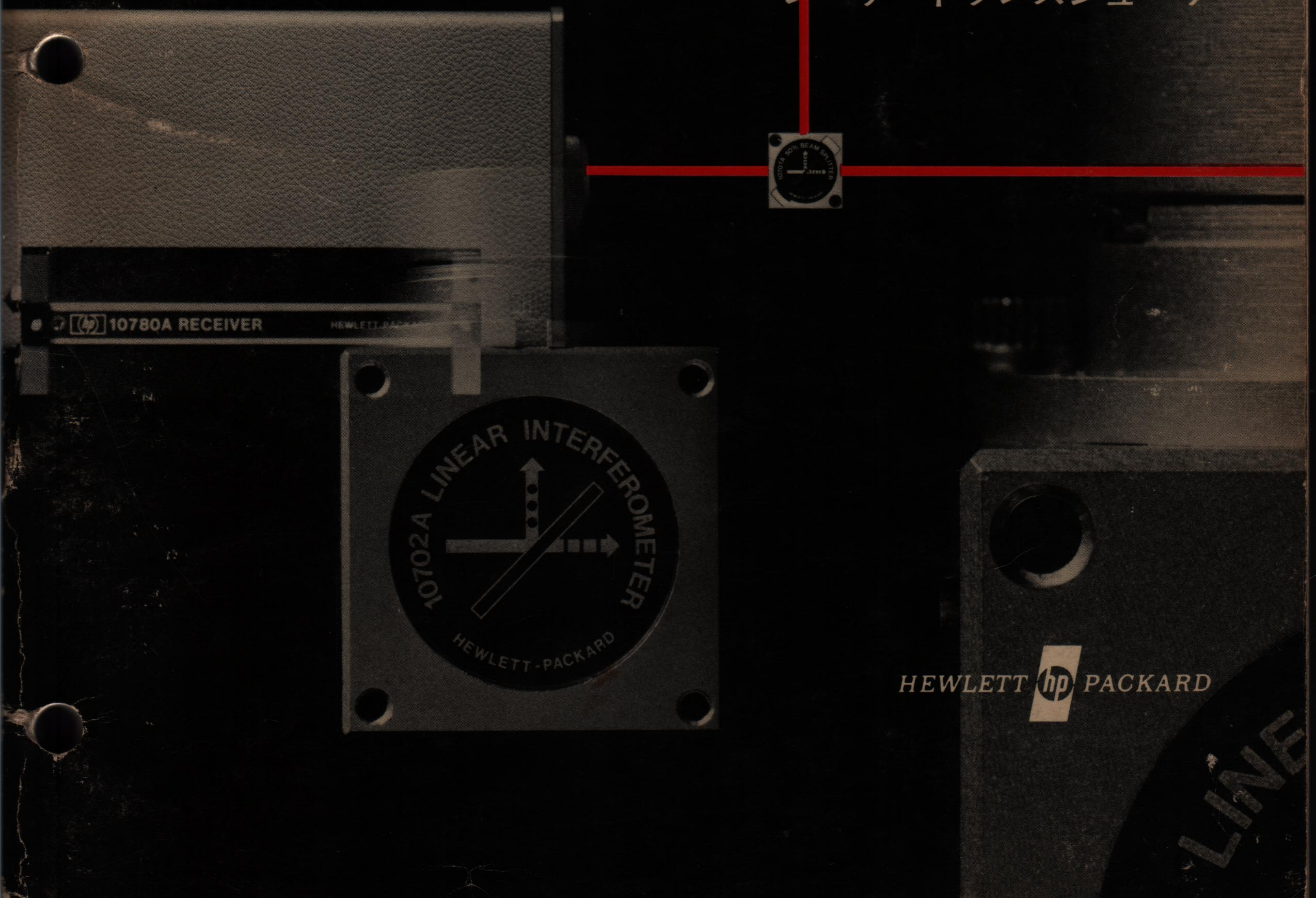
APPLICATION NOTE 197–2

Laser and Optics

5501A

LASER TRANSDUCER
TRANSDUCTEUR A LASER
TRASDUTTORE DA LASER
TRANSDUCTOR DE LASER
LASER TRANSDUCER
レーザ・トランスジューサ



HEWLETT hp PACKARD

Laser and Optics

1 INTRODUCTION

This application note describes the optical aspect of the Hewlett–Packard 5501A Laser Transducer System. It provides the background information on the physical layout of the Laser Transducer head and the receiver, and the optics necessary to direct the laser beam between them. This information will help the reader to understand, install, and align the HP 5501A Laser Transducer Optics. The material is organized as follows:

a. An overall discussion of what constitutes a basic measurement system. This includes only the optical portion of the Laser Transducer System.

b. Measurement components. Detailed descriptions of the individual measurement components of the Laser Transducer System including dimensions, mounting, and installation information. Also discussed are the allowable measurement configurations for the optical components including interferometers, beam benders, and beam splitters.

c. Accuracy considerations. Deals with factors affecting the ultimate measuring accuracy of the Laser Transducer System. Centers on the effect of the environment under which the measurement is made along with techniques for compensating for these effects. Specific types of measurement errors, including the effect of thermal expansion of the part being measured or cut, are discussed. Consideration is also given to cosine error or errors due to misalignment.

d. System installation. Discussion of how to install the measurement components in actual measurement applications. Consideration of possible combinations to split and direct the laser beam to the measurement location. Also discussed is how to route the laser beam to the measurement location with emphasis on minimizing possible measurement errors. This will include the effect of Abbe errors and thermal instabilities on the measurement process. Techniques for protecting the beam from disruptions such as thermal effects, cutting fluid, and chips which could interrupt the measurement are also discussed.

e. Alignment procedure. General rules for the actual alignment of the Laser Transducer System after it is installed on a machine are discussed. Different techniques of aligning the components, depending upon the installation and accuracy requirements are also covered. Specific examples including a 3-axis measurement application utilizing the linear interferometer and an X–Y stage application using plane mirror interferometers illustrate fundamental techniques which can be applied to most installations.

2 OVERVIEW OF LASER AND OPTICS

The Laser Transducer System is a high accuracy, high resolution measuring system and improper installation or use can degrade measurement accuracy. An understanding of the basic measurement capabilities of the system along with the proper considerations of possible sources of errors prior to installation of the equipment will greatly minimize problems both during installation and during operation.

There are a wide variety of possible configurations for the laser and optics, but all multiaxis configurations have four basic parts in common:

a. A two-frequency laser source (5501A Laser Transducer).
b. A set of splitting and bending optics (10700 series).
c. A set of measurement optics (10700 series).
d. A set of receivers (10780A Receiver).

In addition, an adjustable mount (10710A) is available to facilitate the location and alignment of the splitting and bending optics and the single beam interferometer. Another adjustable mount (10711A) is available for the linear interferometer and the plane mirror interferometer.

3 FUNDAMENTAL MEASUREMENT CONCEPTS

To explain some of the basic measurement principles we will start with a single axis measurement system (*Figure 1*). The 5501A Laser Transducer (laser head) is the reference upon which all measurements are based. Also required is some type of interferometer/retroreflector combination. This can be the 10702A Linear Interferometer and 10703A Retroreflector; the 10705A Single Beam Interferometer and the 10704A Retroreflector; or the 10706A Plane Mirror Interferometer and a flat mirror (user supplied) as the retroreflector. The 10780A Receiver is the only other component required in the basic measurement system. The 10780A Receiver detects the displacement of either the interferometer or retroreflector with respect to each other and generates a measurement signal which is sent to the electronics. There the measurement signal is compared to the reference signal generated by the 5501A Laser Transducer. The comparison of the reference and measurement signals is done by the electronics in order to generate displacement information appropriate to the specific application. Refer to SECTION III for a description of the various system electronics configurations.

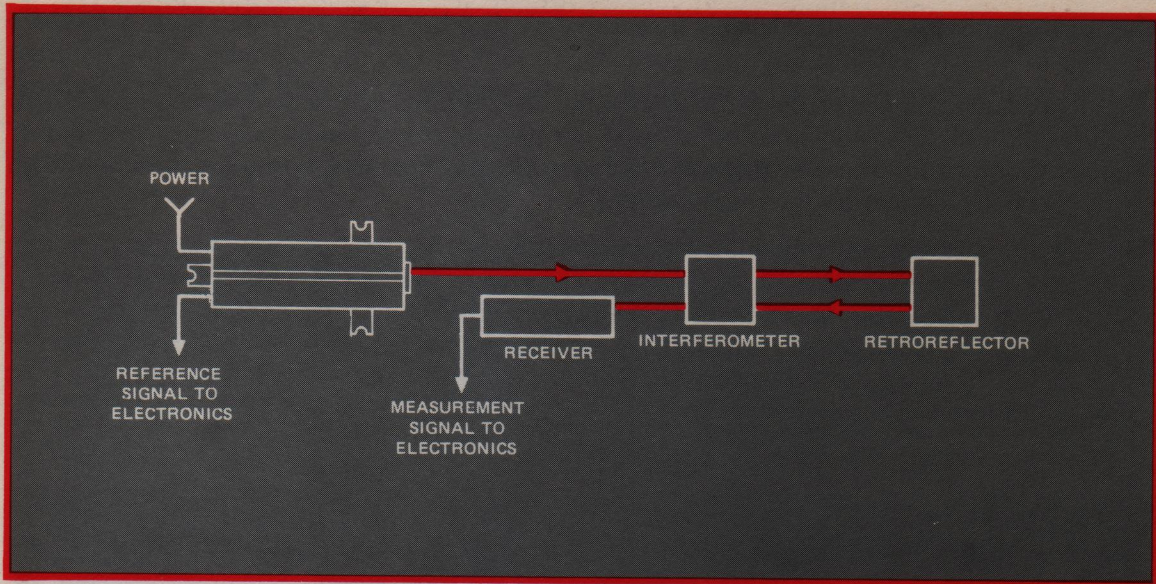


Figure 1. Basic Measurement System

One of the most important concepts which must be understood for successful application of the Laser Transducer System is that it measures only relative position change between the interferometer and the retroreflector. It does not measure absolute position. In addition, the only components sensitive to motion are the interferometer and the retroreflector (*Figure 2*). If the interferometer and retroreflector are fixed in position with respect to each other, there is no knowledge of the absolute distance between the components.

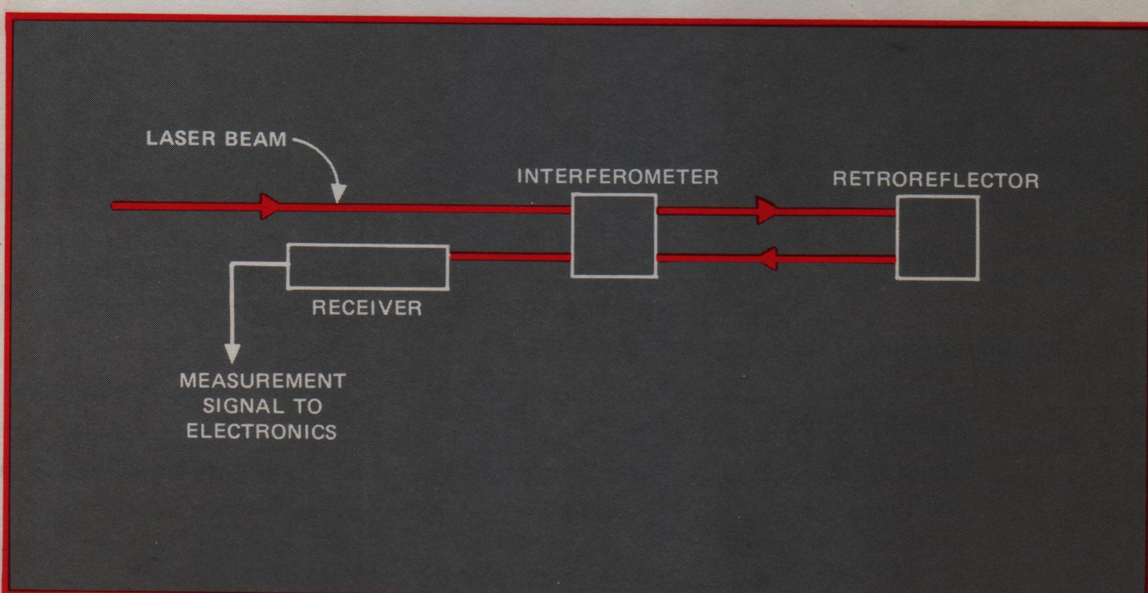


Figure 2. Basic Interferometric Measurements

In the measurement of relative position, it does not matter which component moves as long as one is fixed with respect to the other. If the interferometer is fixed and the retroreflector is the moving component (toward or away from the interferometer) only motion with respect to its original position is detected. Conversely, if the retroreflector is fixed the interferometer can be the moving component.

The measurement system is relatively insensitive to all other motions within limits which are covered in greater detail in following sections. The following brief summary of the different types of motion (see *Figure 3*) is intended only to familiarize you with their effect on a measurement application:

a. Motion of the receiver or laser head in a direction parallel to the measurement path (X) has no effect on the measurement.

b. Motion of the laser head, receiver, interferometer, or retroreflector in a direction lateral to the measurement path (Y or Z) has no effect on the measurement. The only restriction is that sufficient light returns to the receiver. In general, the maximum allowable lateral displacement is 2.5 mm (0.1 inch). Additional lateral movement will normally cause the laser beam to be displaced beyond the point where sufficient light is returned to the receiver.

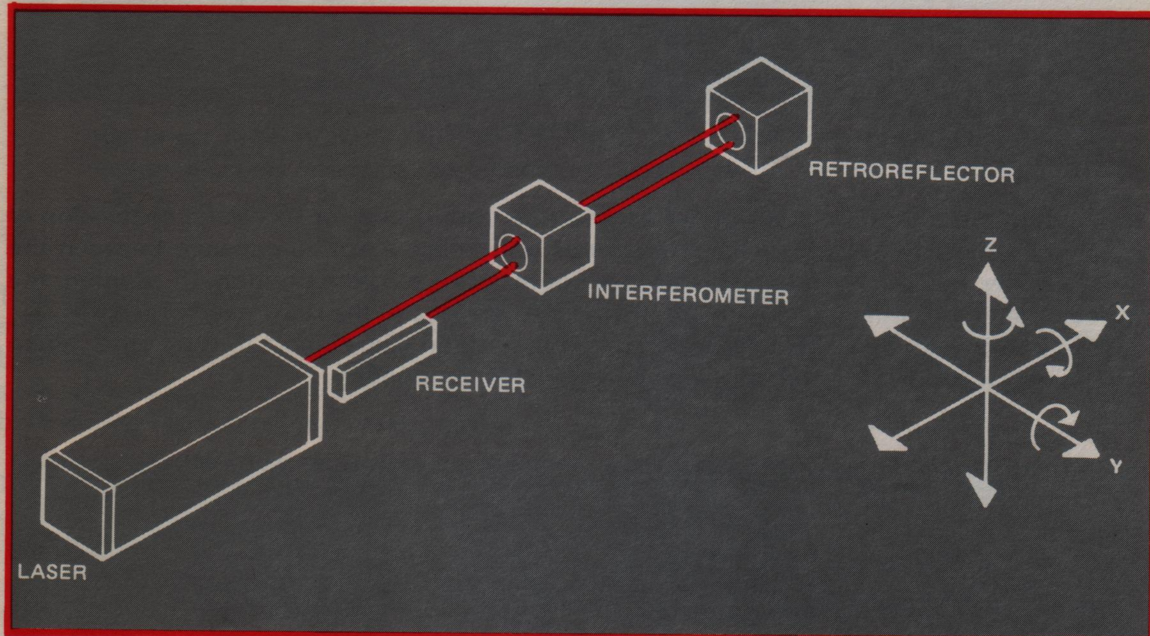


Figure 3. Allowable Component Motions

c. Angular motion of the laser head about the Z and Y axes has two effects:

1. Introduces a measurement error (cosine error) which is discussed in the section on Accuracy Considerations.
2. Can displace the laser beam enough so that insufficient light returns to operate the receiver.

NOTE

Angular motion of the laser head about the X axis is not allowed for reasons described in the section on Measurement Components.

d. Angular motion of the receiver about the X, Y, and Z axes has no effect on the measurement within certain limits (refer to Measurement Components).

e. Angular motions of the interferometer and retroreflector are dependent on the particular components and application. Refer to Measurement Components for limitations.

4 MULTIAXIS MEASUREMENT SYSTEMS

The system is designed to measure up to six independent axes with any combination of interferometers and retroreflectors. In general, the laser measurement concepts discussed above apply equally to any multiaxis measurement system (see *Figure 4*).

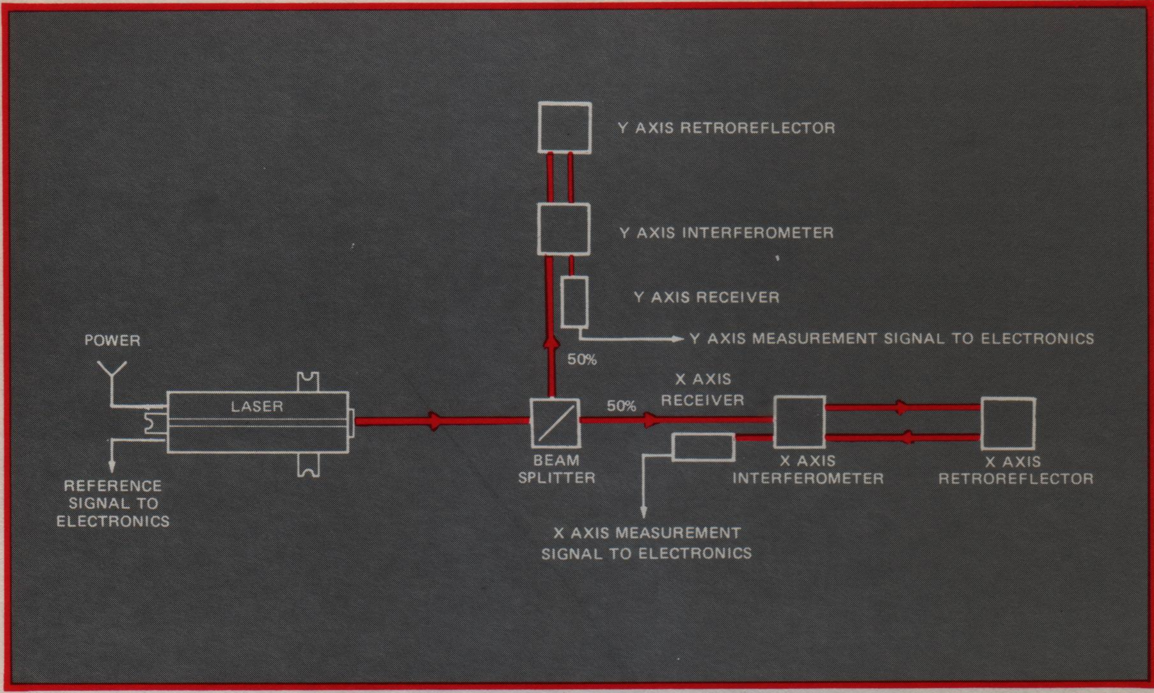


Figure 4. Multiaxis Measurement System

The multiaxis system is similar to the basic measurement system shown in *Figure 1* with the exception that a beam splitter is introduced in the laser beam to provide a second axis of measurement. The X and Y axes are completely independent and generate separate measurement signals. These X and Y measurement signals are compared individually to the reference signal by the electronics to provide displacement data for measurement or control applications. Additional beam splitters can be introduced along with corresponding interferometers, retrorefectors, and receivers to provide up to six measurement axes.

5 MEASUREMENT COMPONENTS

The measurement components comprise that portion of the Laser Transducer System used to generate, direct, and detect the laser beam and consist of the following units:

a. 5501A Laser Transducer
b. 10780A Receiver
c. 10702A Linear Interferometer (and Option 001 Windows)
d. 10703A Retroreflector
e. 10704A Retroreflector
f. 10705A Single Beam Interferometer
g. 10706A Plane Mirror Interferometer
h. 10700A 33% Beam Splitter
i. 10701A 50% Beam Splitter
j. 10707A Beam Bender
k. 10710A Adjustable Mount
l. 10711A Adjustable Mount

5.1 Degrees of Freedom

Prior to covering the individual units a brief discussion of the degrees of freedom that an object (machine table, X-Y stage, etc.) can experience as it slides along a pair of ways will clarify some of the terminology (*Figure 5*). As the object moves linearly in the X-axis direction there are six degrees of motion which will affect the final position of the object. Besides the positioning error along the X-axis which relates directly to the accuracy of the linear scale, the object can also experience angular rotations about the X, Y, and Z axes known as roll, yaw, and pitch, respectively. Pure translational motions in the Y and Z axes are identified as vertical and horizontal out-of-straightness movements respectively. In total, there are six degrees of freedom of motion which will affect the final position of the object as we command it to move in the X direction. If one considers a typical 3-axis positioning system then there are 18 degrees of freedom (6 degrees of freedom per axis) plus errors introduced by out-of-squareness between axes, 21 potential error sources in all, which combine together to define the final position achieved.

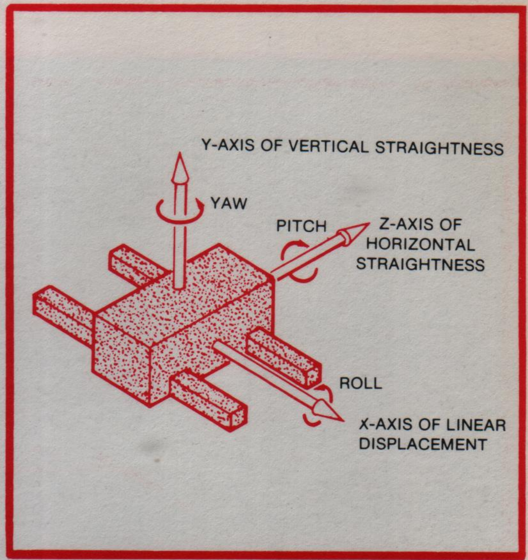


Figure 5. The Six Degrees of Freedom

5.2 General Considerations for Mounting Optics

When deciding where and how to mount the system's optics, keep the following points in mind:

a. Vacuum adhesive with low volatility sealant is used to hold the optical components.

b. Additional information including the method of calculating path loss to ensure that each axis has sufficient beam power is included in Accuracy Considerations.

c. If the laser beam has to go through a window (for example into a vacuum chamber) the window must meet the following requirements:

   1. A minimum window diameter of 25 mm (1 inch) with a minimum thickness of 8 mm (0.3 inch). Larger diameter windows must be proportionally thicker.
   2. A figure of transmission of $\lambda/20$ over 23 mm (0.9 inch).
   3. Parallelism of faces of ±2 minutes.
   4. Surface quality 60–40 per MIL-0-13830.
   5. But most important, be sure there is no strain in the glass.

5.3 5501A Laser Transducer

This paragraph covers only the laser beam orientation and mounting information for the laser head.

The laser head must be positioned so that the beam entering the optical system will be orthogonal with the machine axes. This helps to eliminate cosine error, and can be accomplished with little difficulty (refer to cosine error and alignment procedure). The plane of the laser mounting feet must be roughly parallel (±3°) to either the bottom or sides of the optical component housings (most of which are cube shaped). This guarantees that the polarizing axes of the interferometers are oriented properly relative to the polarization vectors of the laser beam (*Figure 6*).

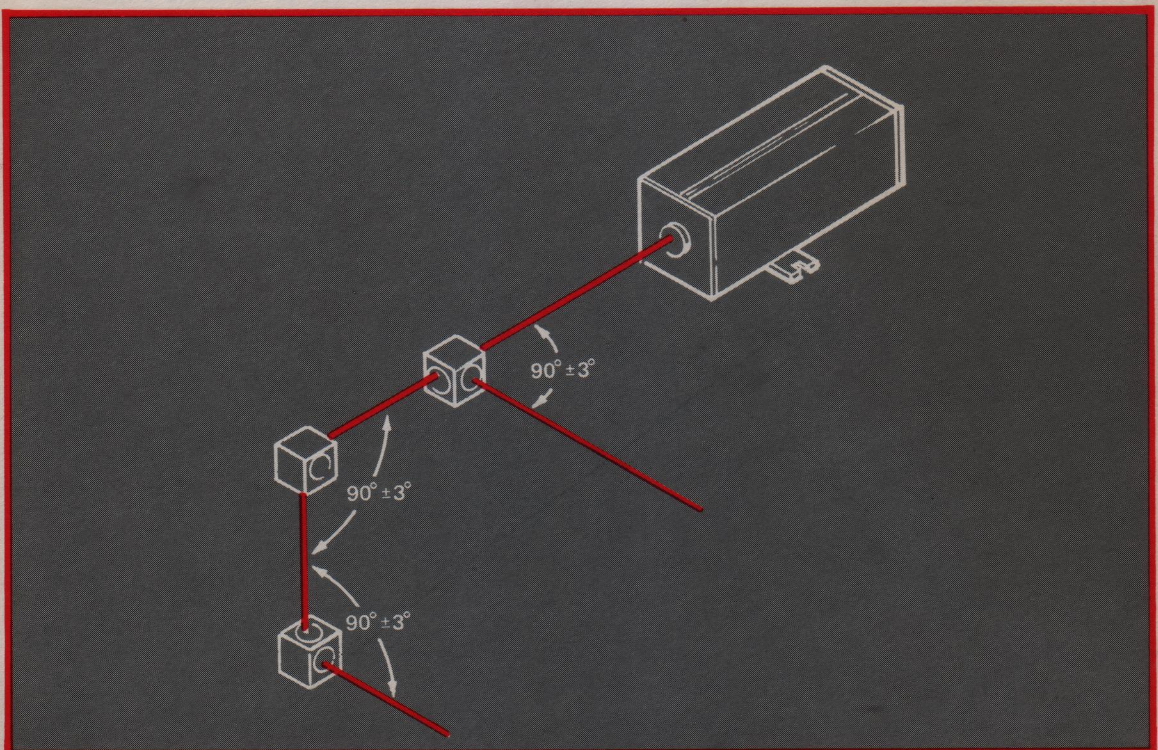


Figure 6. 5501A Laser Transducer Mounting

The laser output has two frequency components, one polarized vertically and one horizontally relative to the plane of the mounting feet. The interferometers work on the assumption that the beam entering them will be polarized vertically and horizontally relative to the interferometers mounting surfaces (*Figure 7*). It does not matter if the polarizations are reversed, only that one be vertical and one horizontal.

The laser can always be rotated in 90° increments about the beam axis (roll) without affecting the transducer performance. If the laser source is deviated in roll, (θ), from one of the four optimum positions, the desired signal in the receiver decreases, and an unwanted null signal starts to appear. To hold the effect on signal-to-noise ratio less than 1 dB (normally an acceptable amount) the laser source must be positioned in roll to within ±3° of one of the four optimum positions. At a θ deviation of 45° the usable signal at the receiver goes to zero.

The laser head dissipates 15 watts. Therefore, on small or very accurate machines care must be exercised in choosing a mounting location and a mounting method. Since the laser tunes itself automatically and continuously from the instant it is turned on (even from a cold start), it can be turned completely off whenever the machine is not being used for a fairly long period of time. This extends slightly the life of the laser tube but may also introduce thermal waves in the machine at start-up, depending on how it is mounted. A separate mounting plate with thermal isolators between the plate and the frame of the machine is generally a good approach. However, this plate must be very rigid to avoid resonance frequency oscillation which might cause a loss of information from a sudden acceleration or a beam displacement.

The displacement information is not affected by vibrations of the laser source or the receiver, but an offset of more than 2.5 mm (0.100 inch) will reduce the amount of light reaching the receiver and make the system more sensitive to other sources of attenuation.

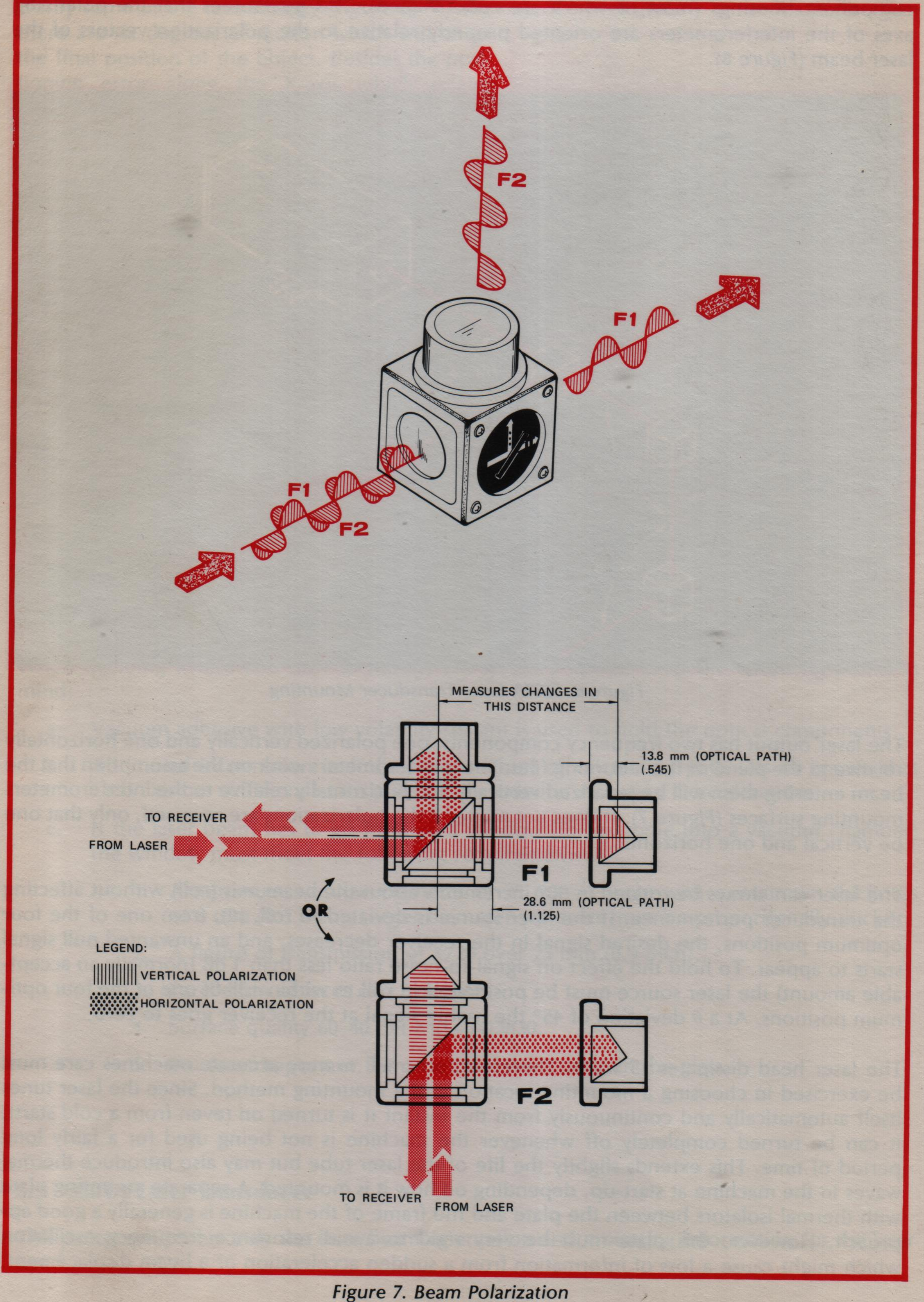


Figure 7. Beam Polarization

The laser head may be used upside down or on its side but must be fastened using the 3 feet. Or, if the feet are removed, use only the 8–32 UNC tapped holes under the bases (*Figure 8*).

a. Allow 50 mm (2 inches) clearance around the laser head for easy service.

b. To maintain good pointing stability it is good practice to use kinematic mounting principles. For example, a 10 arcsecond drift error in the pointing stability of the laser head causes a beam displacement of over 0.01 inch at the receiver if the cube-corner is at a distance of 100 feet.

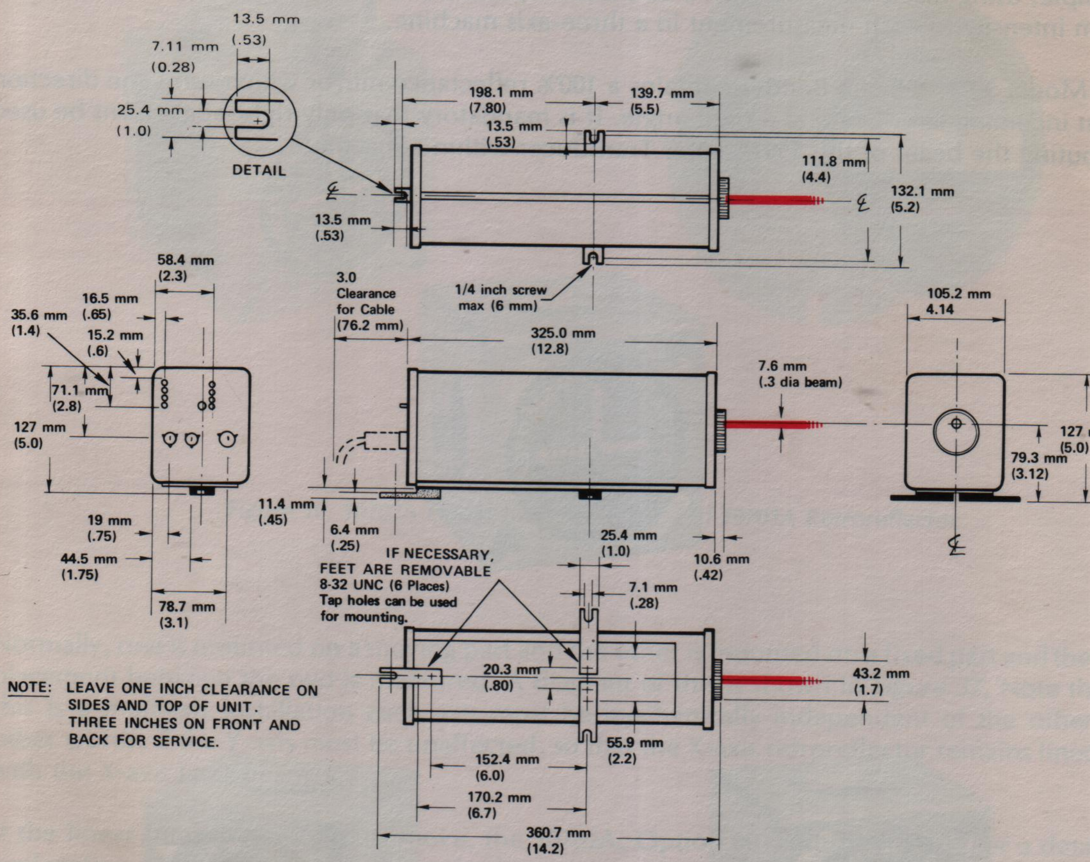


Figure 8. 5501A Laser Transducer Dimensions

5.4 Splitting and Bending Optics (*Figure 9*)

The splitting and bending optics consist of the following units:

a. 10700A 33% Beam Splitter
b. 10701A 50% Beam Splitter
c. 10707A Beam Bender

These 25 mm (1 inch) cubes are designed to allow a portion of the laser beam of the 5501A Laser Transducer to be directed along each measurement axis. Since they are to be mounted within a machine, they are designed for ease and flexibility in mounting and for durability.

The Model 10700A 33% Beam Splitter deflects about one-third of the laser beam intensity at right angles to the original beam direction, allowing the remaining two-thirds to continue. The Model 10701A 50% Beam Splitter deflects half of the laser beam at a right angle and passes the remaining half. Combinations of these two accessories allow some flexibility in directing the desired fraction of beam intensity to each axis of a multiaxis configuration. For example, using first a 33% and then a 50% Beam Splitter, one can direct one-third of the laser beam intensity to each measurement in a three-axis machine.

The Model 10707A Beam Bender contains a 100% reflectance mirror which turns the direction of an incoming laser beam at a right angle. It is mandatory that only right-angle turns be used in routing the beam of the 5501A Laser Transducer within a machine.

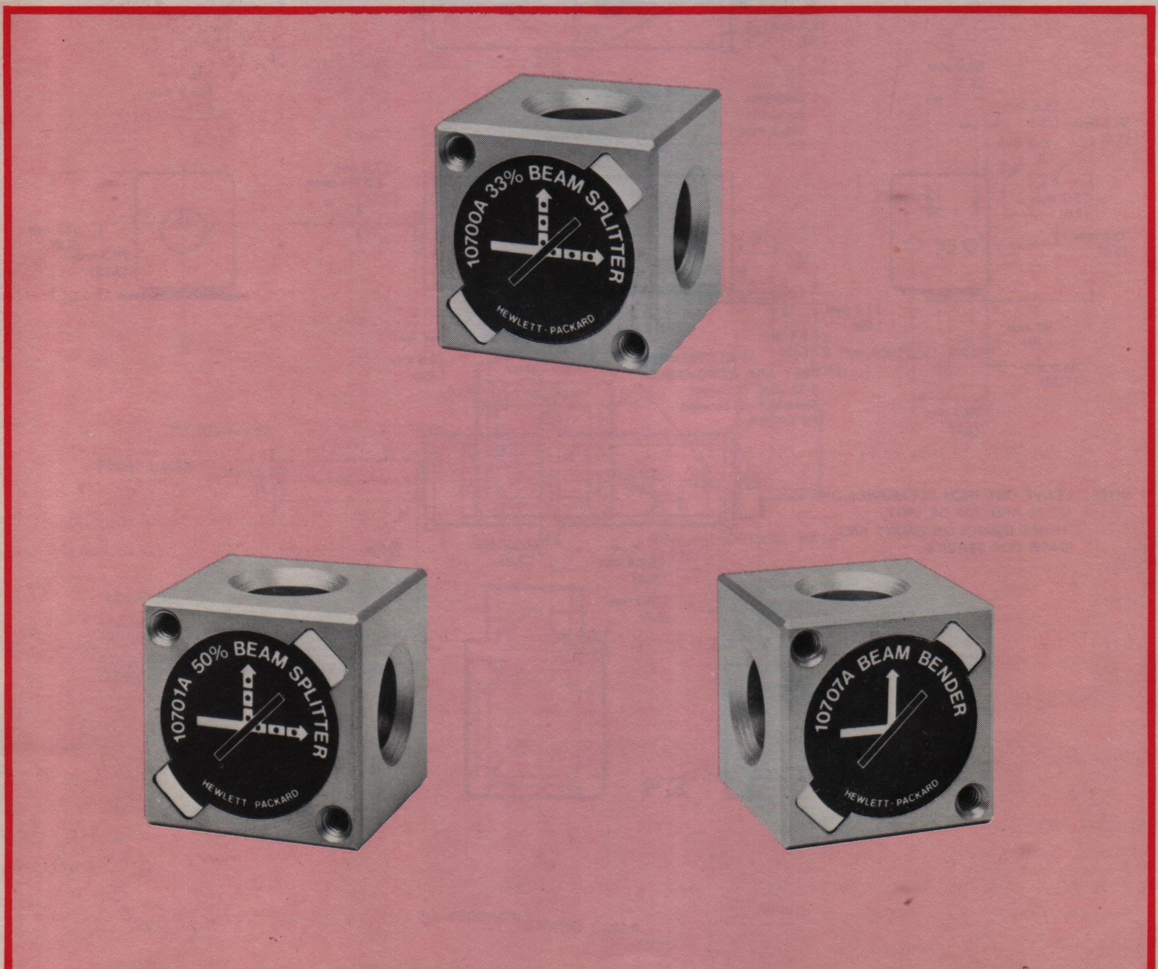


Figure 9. Splitting and Bending Optics

5.5 Measurement Optics

Each Laser Transducer axis must have an interferometer and a retroreflector. Machine design considerations determine which type of interferometer is optimum. The choice of the interferometer for each axis usually specifies the retroreflector for that axis.

5.5.1 10702A LINEAR INTERFEROMETER AND 10703A RETROREFLECTOR (*Figure 10*). The 10702A Linear Interferometer is the lowest cost unit and is used whenever possible for that reason. The measurement retroreflector for this interferometer is the 10703A Retroreflector. Displacement is measured between the interferometer and the cube corner. Either one or both can move.

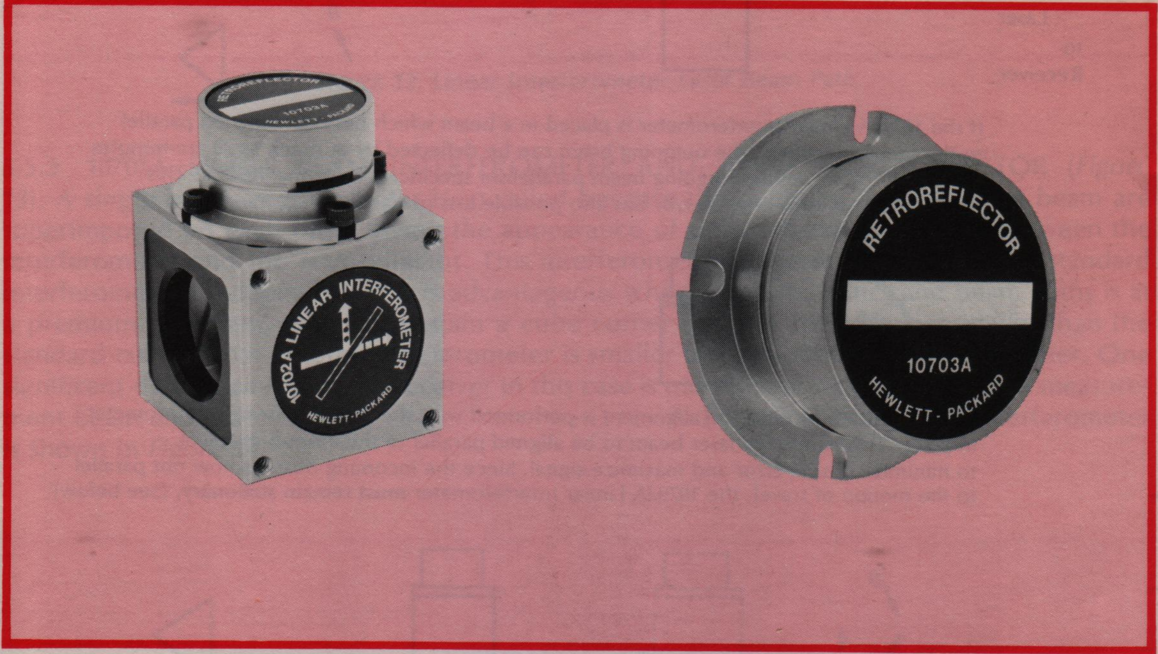


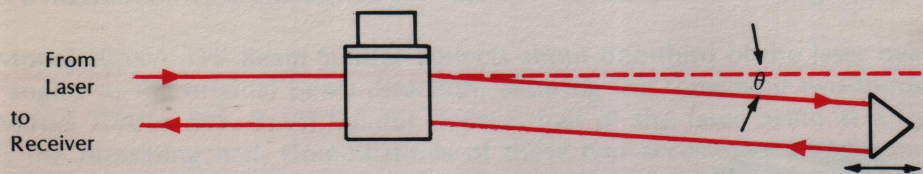
Figure 10. 10702A Linear Interferometer and 10703A Retroreflector

Normally, one is mounted on a moving part and the other is mounted on a fixed part and the displacement between the two is measured. A diagram of this is shown in *Figure 37*. Note that if this is a multiaxis installation each axis must be mechanically independent of the other. In other words, if the Y-axis must be unaffected, so that the X-axis retroreflector remains lined up with the X-axis laser beam.

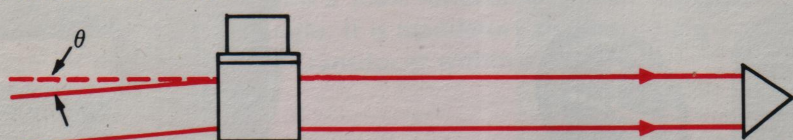
If the linear interferometer must move, the 10702A, Option 001, must be used. For a detailed explanation of why this option is required see *Figure 11*.

5.5.2 LINEAR INTERFEROMETER LASER BEAM PATH. The beam exiting from the laser head is split at the surface of a polarizing beam-splitter, with one frequency reflected to the reference cube corner mounted on the housing (*Figure 12*). The other frequency is transmitted to the 10703A Retroreflector and returned parallel to, but displaced from, the outgoing beam. Both frequencies are reflected back along a common axis to the photodetector in the receiver, with one frequency including a Doppler frequency shift whenever the 10703A Retroreflector (or 10702A Linear Interferometer) moves.

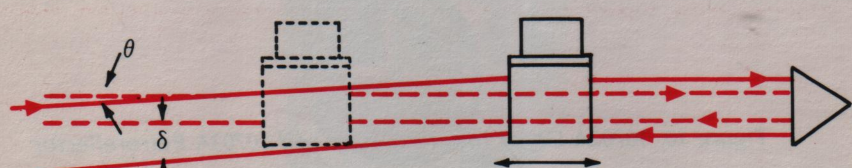
10702A LINEAR INTERFEROMETER
Option 001



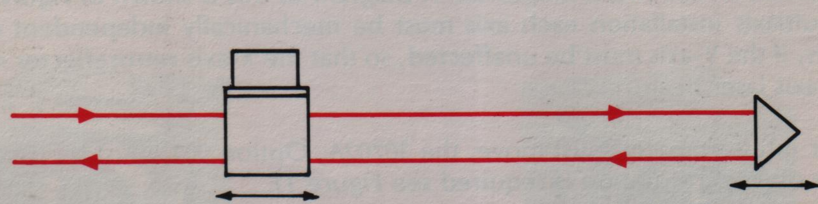
If the 10702A Linear Interferometer is placed in a beam which has been aligned parallel to the motion of travel, the outgoing beam can be deflected by as much as 20 arc-minutes (θ) due to the incoming-outgoing beam parallelism specifications of the 10702A. This could cause not only cosine error but also possible loss of signal during movement of the 10703A Retroreflector.



To compensate for this, the alignment is performed with the 10702A Linear Interferometer in place. This allows the laser beam to be aligned parallel to the motion of travel to minimize cosine error and maximize signal. Since the incoming beam is now not parallel to the motion of travel, the 10702A Linear Interferometer **must remain stationary.** (See below)



If the 10702A Linear Interferometer is moved during the measurement instead of the 10703A Retroreflector, the beam in the measurement path will remain parallel but will be displaced. This displacement δ will occur at the receiver causing a decrease and eventual loss of signal depending on the distance traveled.



If motion of the Linear Interferometer is required, the 10702A Option 001 should be used. This provides special wedge windows which makes the outgoing beam parallel to the incoming beam. This allows motion by either the 10703A Retroreflector or the 10702A Option 001 Linear Interferometer.

Figure 11. 10702A Linear Interferometer with Option 001 Windows

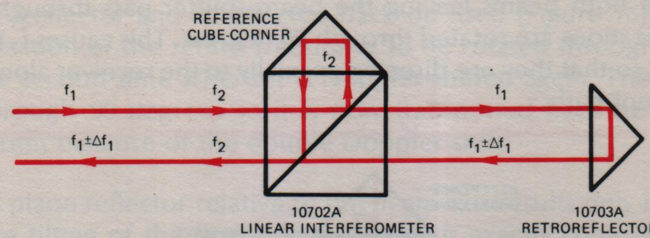


Figure 12. Linear Interferometer Laser Beam Path

5.5.3 10705A SINGLE BEAM INTERFEROMETER AND 10704A RETROREFLECTOR (*Figure 13*). A single beam interferometer is so called because the outgoing and returning beam are superimposed on each other giving the appearance of only one beam traveling between the interferometer and the retroreflector. This interferometer operates the same as the standard interferometer functionally but it is advantageous when space for optics and beam paths is at a premium. The retroreflector is again a cube corner but it is considerably smaller than the standard cube corner and the interferometer is smaller than the standard interferometer. One significant difference is that the receiver in this case is mounted at right angles to the measurement beam and the **interferometer cannot be moved.** A diagram of this type of interferometer is shown in *Figure 14*.

10705A Single Beam Interferometer

10704A Retroreflector

Figure 13. 10705A Single Beam Interferometer and 10704A Retroreflector

5.5.4 SINGLE BEAM INTERFEROMETER LASER BEAM PATH. A polarizing beam-splitter reflects f_2 to the reference cube corner and transmits f_1 to the 10704A Retroreflector or other surface whose displacement is being measured (*Figure 14*). The return path is superimposed on the outgoing path. Since both beams leaving the beam-splitter pass through a quarter-wave plate the returning polarizations are rotated through 90 degress. This causes f_2 to be transmitted and $f_1 \pm \Delta f$ to be reflected so that they are directed coaxially to the receiver along a path perpendicular to the measurement path.

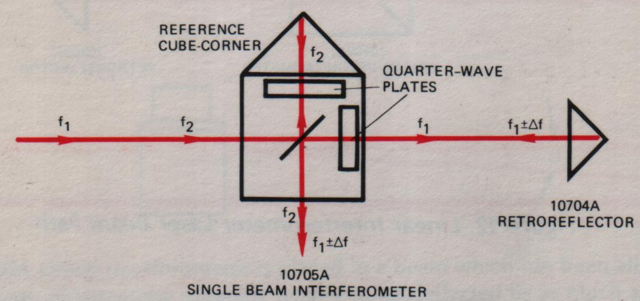


Figure 14. Single Beam Interferometer Laser Beam Path

5.5.5 10706A PLANE MIRROR INTERFEROMETER (*Figure 15*). The plane mirror interferometer has a unique feature in that the retroreflector can be a flat mirror and it has a particular advantage in that interference fringes can still be detected even if the measurement beam is not at a perfect right angle to the mirror. It is an advantage to use plane mirrors as retroreflectors because (in a two-axis system for example) the X retroreflector can be allowed to move in the Y direction without affecting the signal strength or the X measurement. Therefore both retroreflectors of a two-axis system can be mounted on the same moving part. This makes it very easy to eliminate Abbe offset on a two-axis system. If the measuring point is defined to be where the two axis beams cross, the measurement is essentially independent of yaw of the moving stage. Such a design is shown in *Figure 44*. Contrasting this system to a two-axis system using standard interferometers, we see that (if standard interferometers are used) the X-axis retroreflector must be mounted on a part of the stage which moves only in the X direction and never in the Y direction. Also, the Y-axis retroreflector must be mounted on a different part of the stage which is allowed to move only in the Y direction and never in the X direction. Therefore, the two-axis measurements cannot be made on the same part of the stage and there is by necessity some geometry error in the system if it is not perfectly rigid. Another difference between the plane mirror interferometer and the previous two types is that with a plane mirror interferometer the measurement beam travels between the interferometer and the retroreflector twice and therefore the resolution is twice that of the other interferometers. To be specific, the standard interferometer and single beam interferometer have a resolution of 0.16 micrometre (6 μinches) without electronic resolution extension, whereas the plane mirror interferometer has a resolution of 0.08 micrometre (3 μinches) without electronic resolution extension. All three of these interferometers are used to measure linear displacement.

Figure 15. 10706A Plane Mirror Interferometer

5.5.6 PLANE MIRROR INTERFEROMETER LASER BEAM PATH (*Figure 16*). The beam entering the interferometer is split into f_1 and f_2, with f_2 returning to the receiver after retroreflection by the reference cube corner. As in the linear interferometer, f_1 is transmitted out to the plane retroreflector and is reflected back on itself (*Figure 16*). The quarter-wave plate causes the polarization of the return frequency to be rotated through 90 degrees so the $f_1 \pm \Delta f$ is reflected out a second time where it is Doppler shifted again. The polarization of $f_1 \pm 2\Delta f$ is rotated again through 90 degrees so it is now transmitted back to the receiver. Resolution doubling is inherent because of the double Doppler shift.

Any tilting of the plane reflector relative to the beam axis results only in an offset of the return, not in a tilt, since tilting of the first reflected beam is exactly compensated by the second reflection. See *Figure 23* for plane mirror specifications.

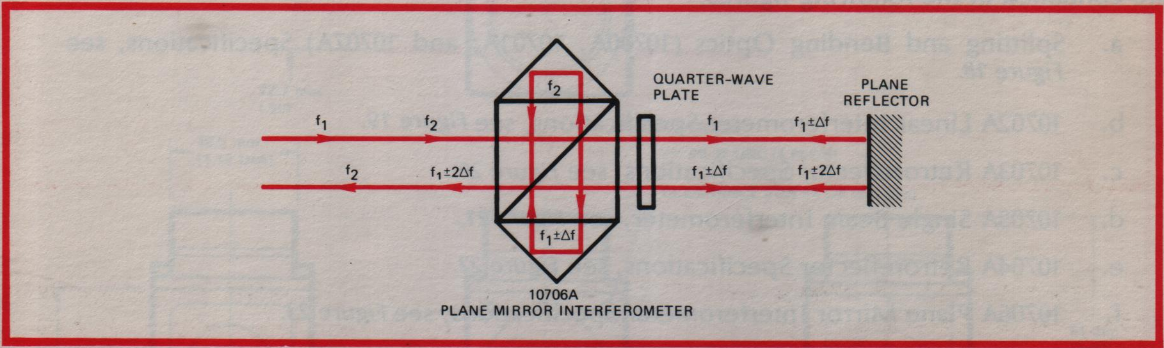


Figure 16. Plane Mirror Interferometer Laser Beam Path

5.5.7 10710A AND 10711A ADJUSTABLE MOUNTS (*Figure 17*). The 10710A and 10711A Adjustable Mounts provide a convenient means of mounting, aligning, and securely locking in position the optical accessories to the 5501A Laser Transducer System. Since both mounts allow approximately ±8° in the tilt adjustment and ±4° in the yaw adjustment, the need for custom fixturing is minimized on most installations. A unique feature of these mounts allows the component being adjusted to be rotated about its optical centerline providing simple, timesaving installations. The 10710A Adjustable Mount will accept the 10700A and 10701A Beam Splitters, the 10705A Single Beam Interferometer, and the 10707A Beam Bender. The 10711A Adjustable Mount will accept the 10702A Linear Interferometer and the 10706A Plane Mirror Interferometer. Mounting screws are provided to attach the optical components to the mount.

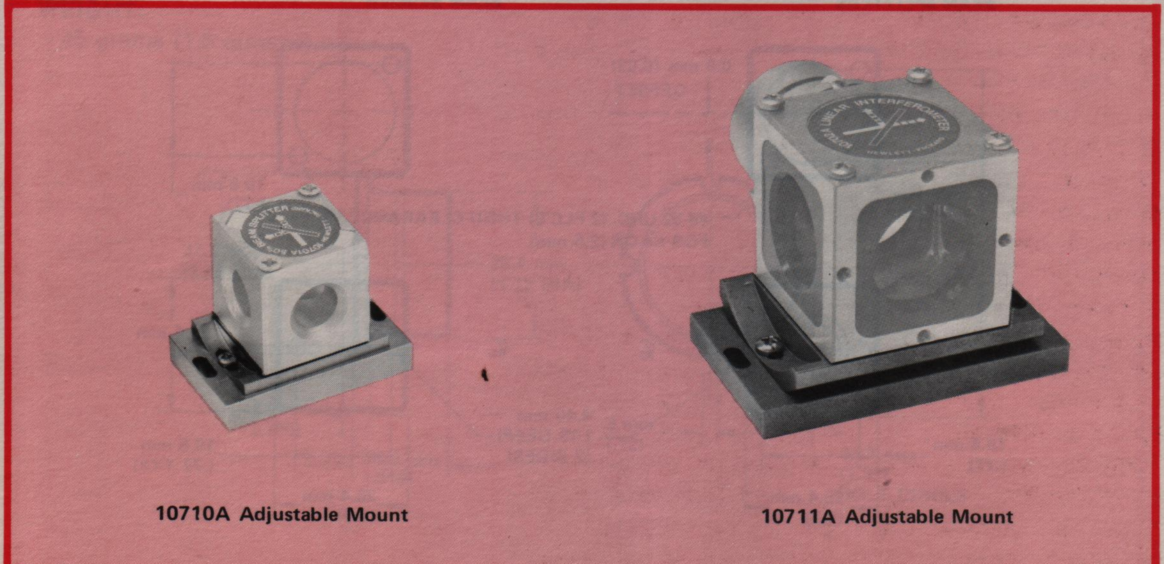


Figure 17. 10710 and 10711A Adjustable Mounts

The thickness of the 10711A mount is such that the beam centerline corresponds to the lower part of the 10701A or 10706A interferometers. To be in line with the center of the interferometer a spacer 6.4 mm (1/4 inch) thick has to be added to the laser head, or to be in line with the upper part, a 12.7 mm (1/2 inch) spacer is needed. Also remember as the beam goes through a beam splitter, the exit beam is slightly offset downward (or to the side if the beam is bent in the horizontal axis) by 0.8 mm (.03 inch). See *Figure 18*.

Both mounts are made of stainless steel 416. Its magnetic properties can be helpful at the design stage if magnetic clamps are used. However, in final installation, secure the mount with the provided screws.

5.5.8 SPECIFICATIONS OF INDIVIDUAL UNITS. The specifications for the individual units are contained in the following figures:

a. Splitting and Bending Optics (10700A, 10701A, and 10707A) Specifications, see *Figure 18*.

b. 10702A Linear Interferometer Specifications, see *Figure 19*.

c. 10703A Retroreflector Specifications, see *Figure 20*.

d. 10705A Single Beam Interferometer, see *Figure 21*.

e. 10704A Retroreflector Specifications, see *Figure 22*.

f. 10706A Plane Mirror Interferometer Specifications, see *Figure 23*.

g. 10710A and 10711A Adjustable Mounts Specifications, see *Figure 24*.

WEIGHT:
(All Models) 90 grams (3.2 ounces)
DIMENSIONS:
See dimensional drawings.

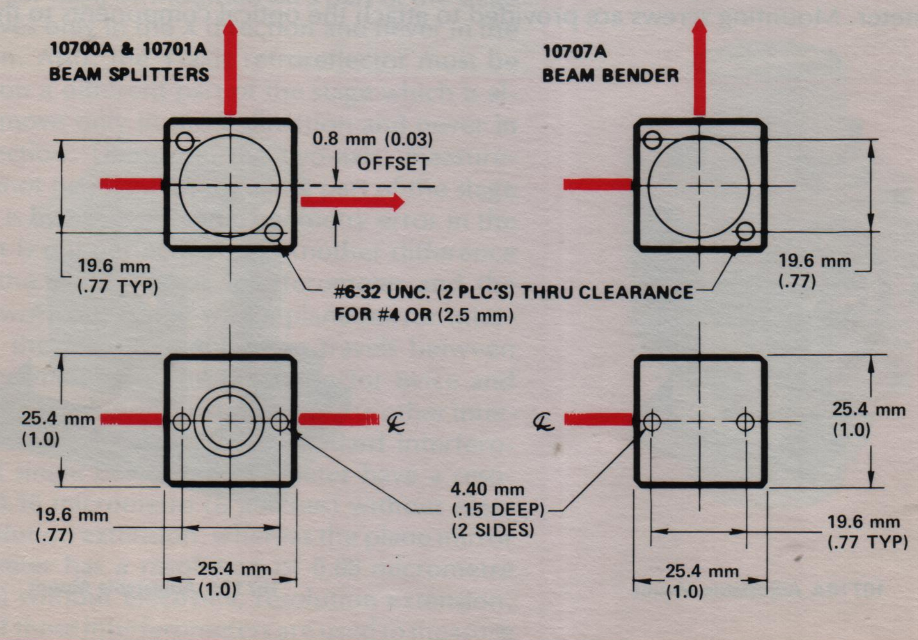


Figure 18. Splitting and Bending Optics (10700A, 10701A, and 10707A) Specifications

WEIGHT:
230 grams (8 ounces)
DIMENSIONS:
See dimensional drawing.

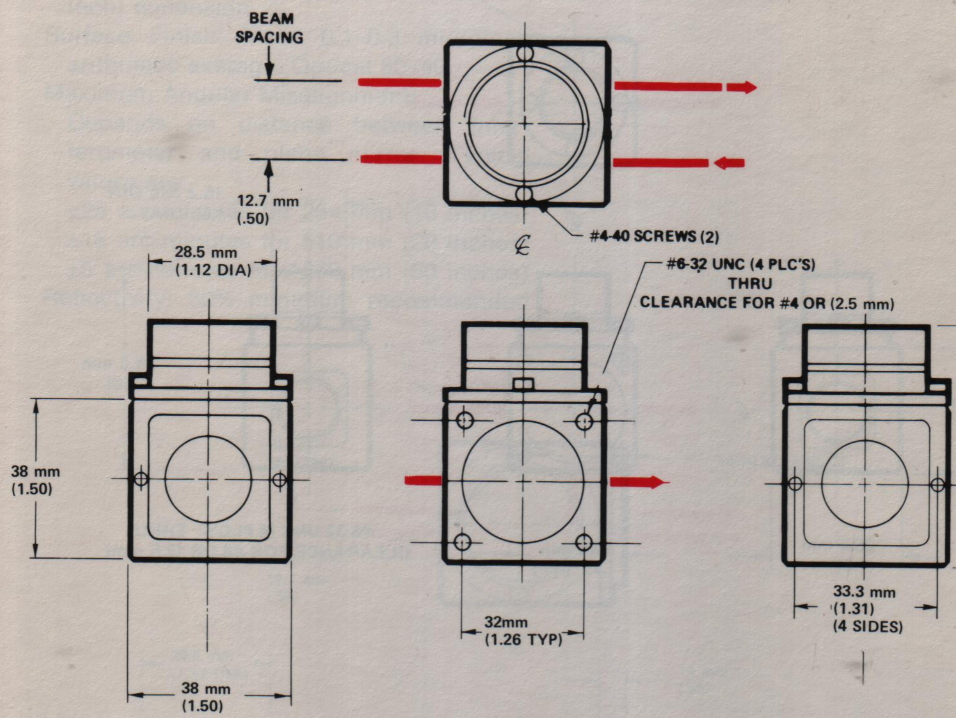


Figure 19. 10702A Linear Interferometer Specifications

WEIGHT:
45 grams (1.6 ounces)

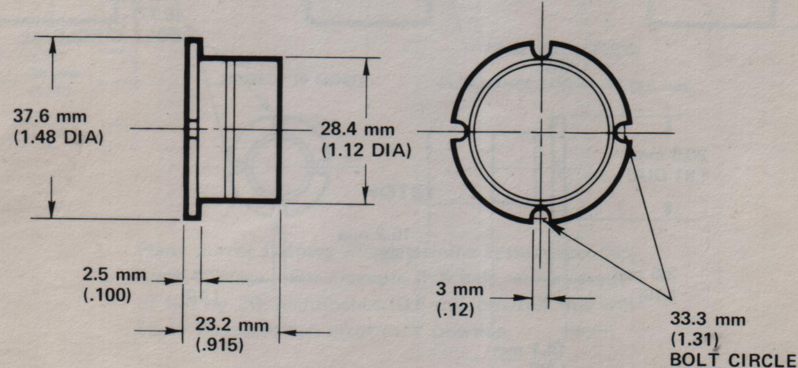


Figure 20. 10703A Retroreflector Specifications

WEIGHT:
90 grams (3.2 ounces)
DIMENSIONS:
See dimensional drawing.

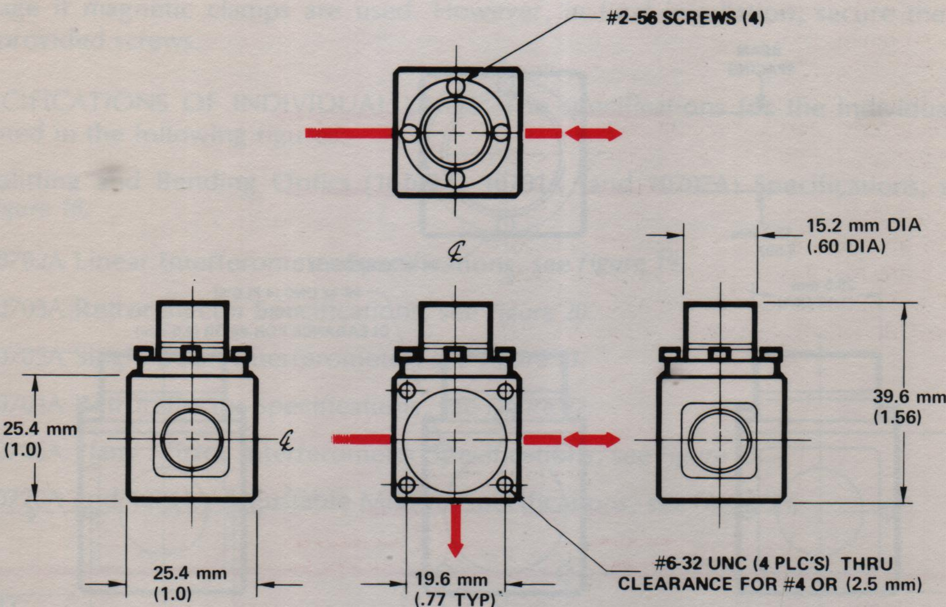


Figure 21. 10705A Singel Beam Interferometer Specifications

WEIGHT:
23 grams (0.8 ounces)
DIMENSIONS:
See dimensional drawing.

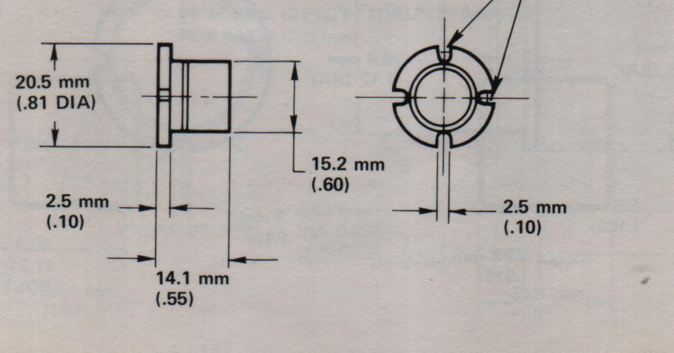


Figure 22. 10704A Retroreflector Specifications

WEIGHT:

11.2 ounces (316 grams)

DIMENSIONS:

See dimensional drawing.

REFLECTOR REQUIREMENTS:

Flatness: Must not deviate from a best-fit plane by more than 0.1 micrometre (3 microinches) over any 20 mm (0.8 inch) dimension.

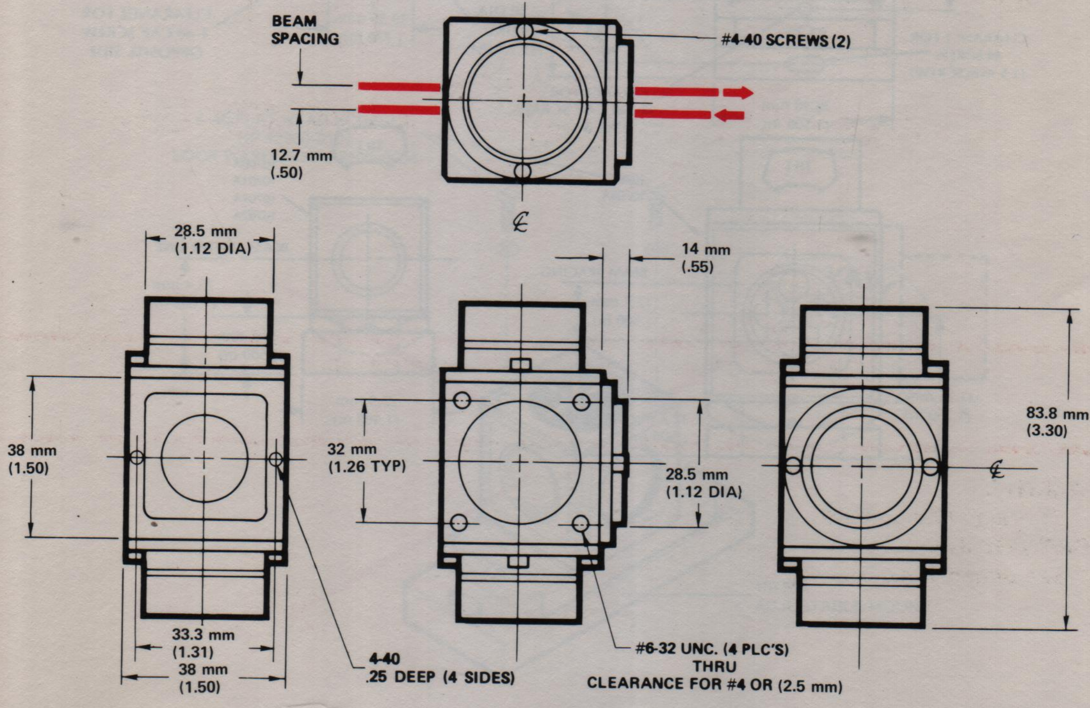
Surface Finish: Metal 0.1–0.3 microinch arithmetic average. Optical 80–40.

Maximum Angular Misalignment:

Depends on distance between interferometer and plane mirror. Typical values are:

±25 arc-minutes for 254 mm (10 inches)
±15 arc-minutes for 510 mm (20 inches)
±5 arc-minutes for 1270 mm (50 inches)

Reflectivity: 80% minimum recommended



NOTE

Plane mirror flatness will determine system accuracy for X-Y stage. For example if X axis mirror is out of flat by 20 microinches (0.5 micrometre) this will cause 20 microinch error in Y position.

Figure 23. 10706A Plane Mirror Interferometer Specifications

WEIGHT:

Model 10710A: 113 g (4 oz.)
Model 10711A: 198 g (7 oz.)

DIMENSIONS:

See dimensional drawings.

ADJUSTMENTS:

±8° Yaw
±4° Tilt

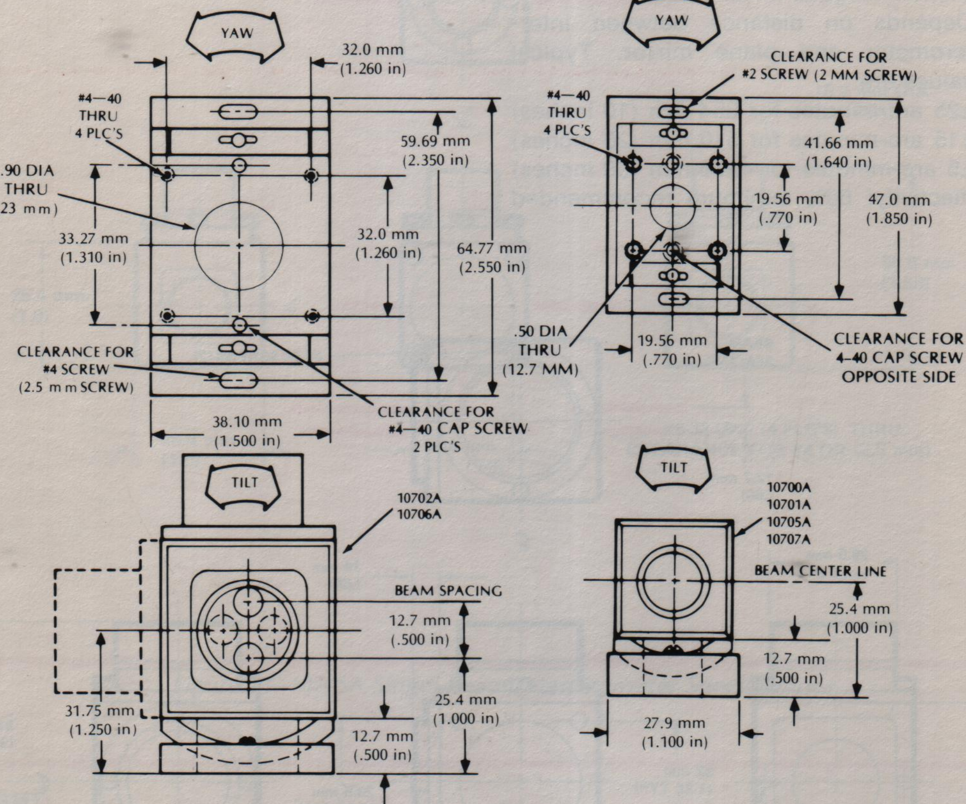


Figure 24. 10710A and 10711A Adjustable Mounts Specifications

5.6 Typical Mounting of Optics

The following figures show some methods of mounting the optics using the adjustable mounts:

a. *Figure 25* shows how to mount the splitting and bending optics or the single beam interferometer in the horizontal and vertical planes using the 10710A Adjustable Mount.

b. *Figure 26* shows how to mount the linear or the plane mirror interferometer in the horizontal plane using the 10711A Adjustable Mount.

c. *Figure 27* shows how to mount the linear or the plane mirror interferometer in the vertical plane using the 10711A Adjustable Mount.

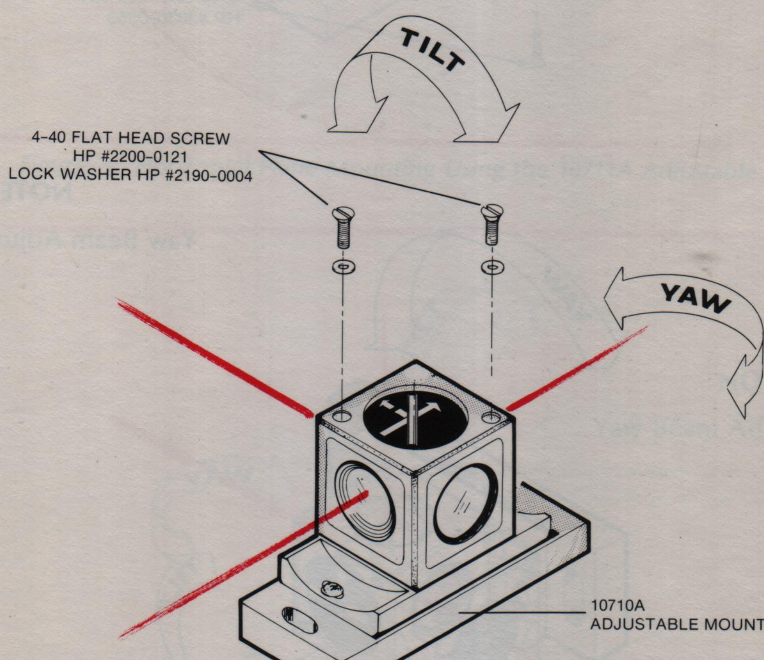


Figure 25. Horizontal and Vertical Plane Mounting Using the 10710A Adjustable Mount

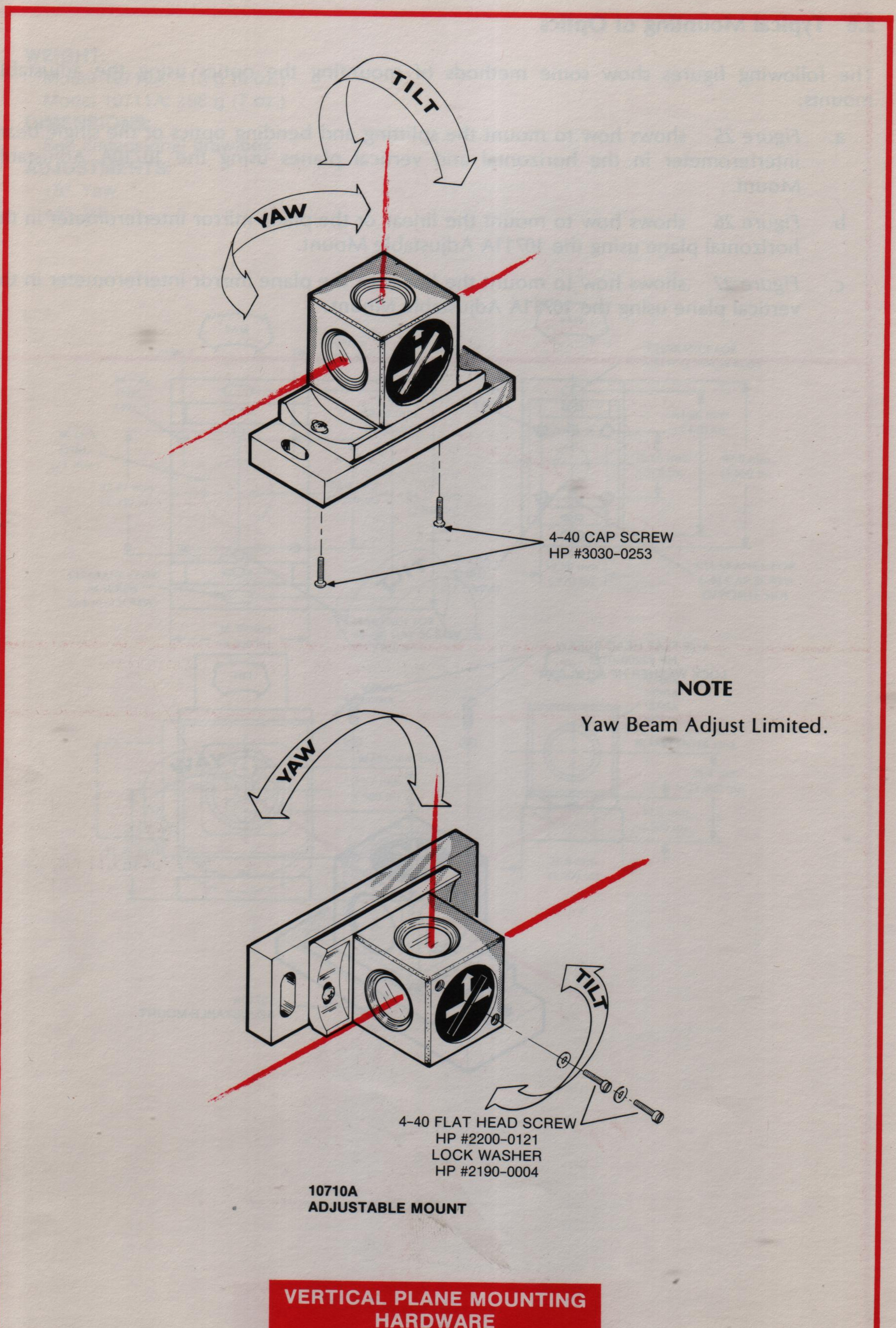


Figure 25. Horizontal and Vertical Plane Mounting Using the 10710A Adjustable Mount (Cont'd)

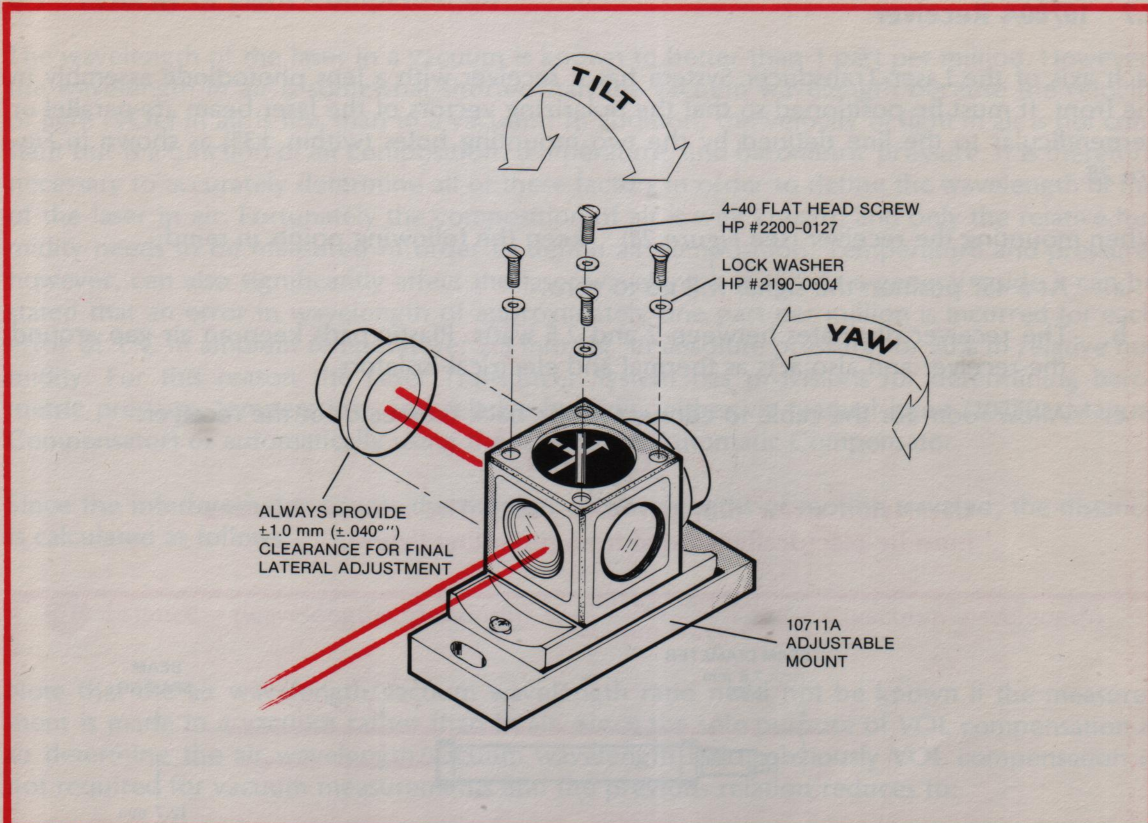
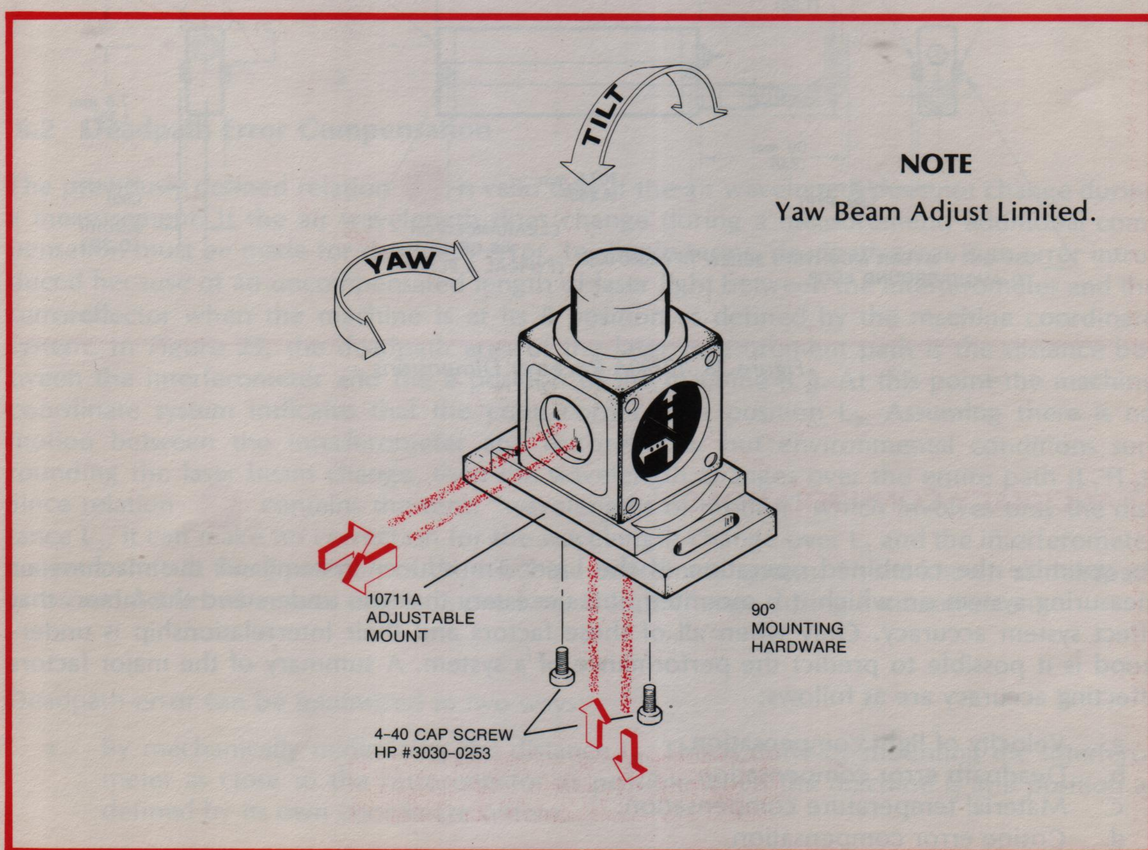


Figure 26. Horizontal Plane Mounting Using the 10711A Adjustable Mount



NOTE

Yaw Beam Adjust Limited.

Figure 27. Vertical Plane Mounting Using the 10711A Adjustable Mount

5.7 10780A Receiver

Each axis of the Laser Transducer System has a receiver with a lens photodiode assembly in the front. It must be positioned so that the polarizing vectors of the laser beam are parallel or perpendicular to the line defined by the two mounting holes (within ±3°) as shown in *Figure 28*.

When mounting the receiver (see *Figure 28*) keep the following points in mind:

a. At a 45° position the signal will go to zero.

b. The receiver dissipates between 2 and 2.5 watts. Plastic pads keep an air gap around the receiver and also acts as thermal and electrical isolators.

c. Allow room for the cable to connect to the back connector of the receiver.

CAUTION

Use Nylon screw only (HP 2360-0369). The receiver housing must be electrically isolated from mounting fixture.

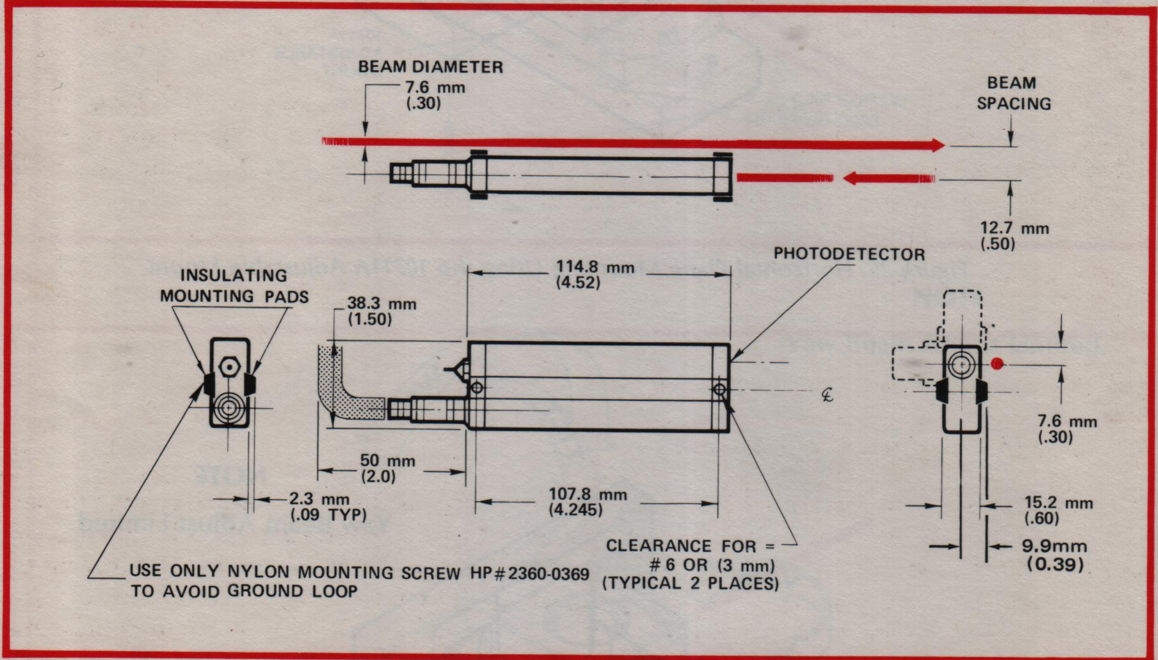


Figure 28. 10780A Receiver Dimensions

6 ACCURACY CONSIDERATIONS

To optimize the combined operation of the Laser Transducer System and the machine or measuring system on which it is mounted, it is necessary that you understand the factors that affect system accuracy. Only when all of these factors and their interrelationship is understood is it possible to predict the performance of a system. A summary of the major factors affecting accuracy are as follows:

a. Velocity of light compensation.
b. Deadpath error compensation.
c. Material temperature compensation.
d. Cosine error compensation.

6.1 Velocity of Light Compensation

The wavelength of the laser in a vacuum is known to better than 1 part per million. However, the wavelength in air is somewhat shorter than the vacuum wavelength because the velocity of light (VOL) in air is less than in a vacuum. In addition, the velocity of light in air is not constant but is a function of air composition, temperature, and barometric pressure. It is therefore necessary to accurately determine all of these factors in order to define the wavelength of the of the laser in air. Fortunately the composition of air is well known, and only the relative humidity needs to be measured in order to define air composition. Temperature and pressure, however, can also significantly affect the laser wavelength in air. As a general guide it can be stated that an error in wavelength of approximately one part per million is incurred for each error of 1°C in ambient temperature; 2.5 mm Hg. in absolute pressure, or 30% in relative humidity. For this reason the Laser Transducer System has provisions for determining barometric pressure, temperature, and relative humidity either via manual input (10756A Manual Compensator) or automatically using the C10–5510A Automatic Compensator.

Since the interferometer counts the number of wavelengths of motion traveled, the distance is calculated as follows:

(1) $$\text{distance} = (\text{wavelengths of motion}) \times \frac{\text{air wavelength}}{\text{vacuum wavelength}} \times (\text{vacuum wavelength})$$

Note that the air wavelength/vacuum wavelength ratio need not be known if the measurement is made in a vacuum rather than in air. Since the sole purpose of VOL compensation is to determine the air wavelength/vacuum wavelength ratio, obviously VOL compensation is not required for vacuum measurements and the previous relation reduces to:

(2) $$\text{distance (in vacuum)} = (\text{wavelengths of motion}) \times (\text{vacuum wavelength})$$

6.2 Deadpath Error Compensation

The previously defined relation (1) is valid only if the air wavelength does not change during a measurement. If the air wavelength does change during a measurement, additional compensation must be made for deadpath error. In simple terms, deadpath error is an error introduced because of an uncompensated length of laser light between the interferometer and the retroreflector when the machine is at its Ø position as defined by the machine coordinate system. In *Figure 29*, the deadpath area of the laser measurement path is the distance between the interferometer and the Ø position of the machine (L_1). At this point the machine coordinate system indicates that the cube corner is at position L_2. Assuming there is no motion between the interferometer and retroreflector but environmental conditions surrounding the laser beam change, then the wavelength changes over the entire path (L_1+L_2). Since relation (1) contains the term "wavelengths of motion" which involves only the distance L_2, it can make no correction for the wavelength change over L_1 and the interferometer causes a shift in the Ø position of the machine coordinate system. This is known as deadpath error and occurs whenever environmental conditions change during a measurement.

Deadpath error can be minimized in two ways:

a. By mechanically minimizing the distance L_1. This is done by mounting the interferometer as close to the retroreflector as possible when the machine is at Ø position as defined by its own coordinate system.

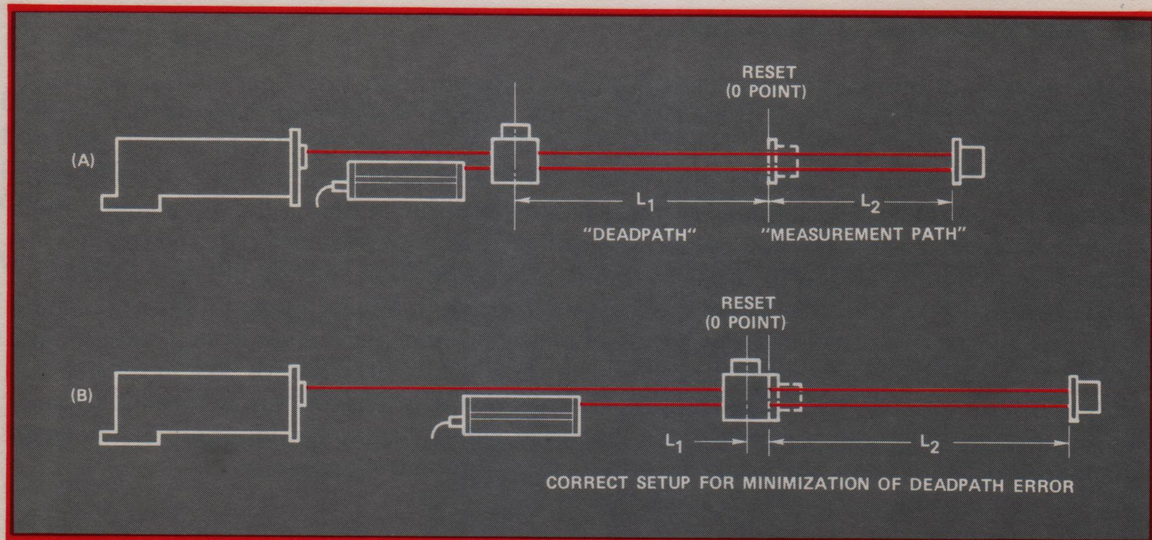


Figure 29. Deadpath Error Compensation

b. By correcting for the residual distance L_1 in software in the case of the Computer Interface Electronics and the Calculator Interface Electronics. Provisions are made for this correction in hardware in the English/Metric pulse output card. In this case relation (1) is expanded to the more general relation:

(3) $$\text{distance} = \left[(\text{quarter wavelengths of deadpath} + \text{quarter wavelengths of motion}) \times \frac{\text{air quarter wavelength}}{\text{vacuum quarter wavelength}} \times \text{vacuum quarter wavelength}\right] - (\text{deadpath in inches or millimetres})$$

You must input the terms "wavelengths of deadpath" and "deadpath in inches or millimetres". These terms can be determined as follows:

$$\text{Quarter wavelengths of deadpath} = 1.6055 \times 10^5\ L_1 \text{ (if } L_1 \text{ is in inches)}$$

or

$$\text{Quarter wavelengths of deadpath} = 6.3211 \times 10^3\ L_1 \text{ (if } L_1 \text{ is in millimetres)}$$

$$\text{Deadpath in inches or millimetres} = L_1 \text{ in inches or millimetres}$$

The deadpath (L_1) need not be measured with high precision. The error in measuring L_1 simply shows up as an uncompensated deadpath (ΔL_1). For example, if the deadpath of a particular machine axis were 10.5 inches but was assumed to be 10 inches then this would result in 0.5 inches (the error in measuring L_1) of uncompensated deadpath. The resulting 0 shift that occurs if environmental conditions changed during a measurement would be:

$$0 \text{ shift} = \Delta L_1 \times (\text{change in air wavelength in parts per million})$$

If atmospheric pressure changed by 0.1 in. Hg, this causes a 1 ppm change in laser wavelength and

$$0 \text{ shift} = 0.5 \text{ in.} \times 1 \text{ ppm} = 0.5 \times 10^{-6} \text{ in.}$$
$$(1 \text{ ppm} = 1 \times 10^{-6} \text{ in./in.} = 1 \times 10^{-6} \text{ mm/mm etc.})$$

The ability to correct for deadpath error in software does not eliminate the necessity of minimizing deadpath by proper location of the interferometer wherever possible. If the deadpath (L_1) is large compared to the distance traveled (L_2), then the predominant error is a 0 shift due to uncertainty in determining the change in air wavelength and this error cannot be eliminated in software.

6.3 Material Temperature Compensation

6.3.1 THERMAL EXPANSION OF THE PART. The previous section discussed compensation to eliminate errors due to a change in the laser wavelength. In addition, it is necessary to compensate for the expansion or contraction of the material of the part being machined or measured as the temperature changes. Strictly speaking, this problem is not related to the Laser Transducer System and occurs regardless of the position sensing transducer used on the machine. It is, however, of such prime importance that it must be understood by the user if he wishes to obtain optimum machine performance. *Figure 30* shows the relative effect of different errors.

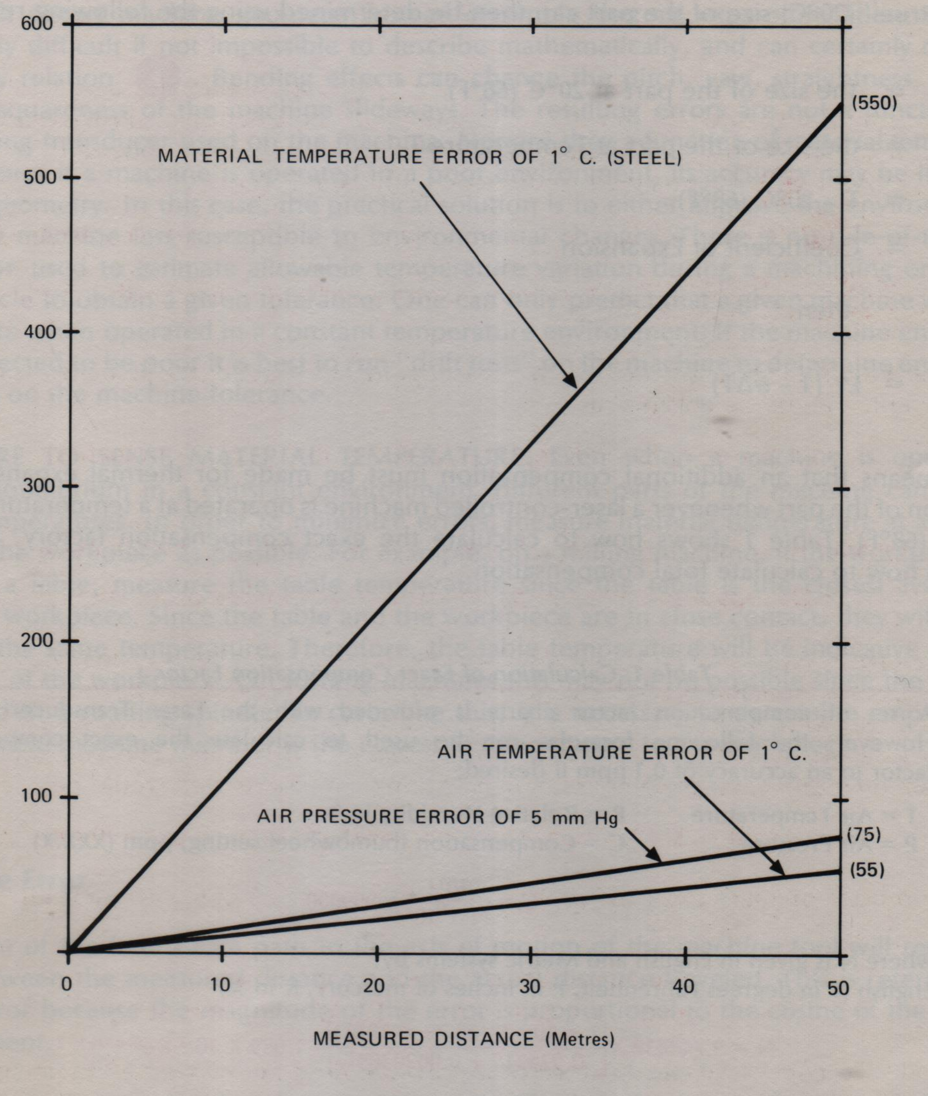


Figure 30. Relative Effect of Errors in Atmospheric and Material Temperature Factors

It is well known that the size of most physical objects changes with temperature. For this reason it was decided that physical length standards must always be measured or compared at a temperature of exactly 20°C (68°F). For example, a "1-inch" gage block is defined to be 1-inch long if (and only if) it is at 20°C. At any other temperature it will probably not be 1-inch long even though it is called a "1-inch" gage block. In addition, if three different "1-inch" gage blocks made of different materials are compared and found to be exactly the same length at 20°C they will not be the same length at any other temperature. For this reason the "true" size of a material object is commonly accepted as the size of the object at 20°C (68°F). In order to accurately machine or measure a part it is recommended that the part be at 20°C during the machining or measuring operation. If the path is not at 20°C its "true" size cannot be defined unless three things are known:

1. The temperature of the part.
2. The size of the part at that temperature.
3. The thermal coefficient of expansion of the part (refer to Appendix D).

The "true" (20°C) size of the part can then be determined using the following relation:

Let

L_O = the size of the part at 20°C (68°F)

L_T = the size of the part at Temperature T

ΔT = T - 20°C (68°F)

α = Coefficient of Expansion

then

4 $$L_O = L_T (1 - \alpha \Delta T)$$

This means that an additional compensation must be made for thermal expansion or contraction of the part whenever a laser-controlled machine is operated at a temperature other than 20°C (68°F). *Table 1* shows how to calculate the exact compensation factory, and *Table 2* shows how to calculate total compensation.

Table 1. Calculation of Exact Compensation Factor

A set of compensation factor charts is provided with the Laser Transducer System. However, the following formulas can be used to calculate the exact compensation factor to an accuracy of 0.1 ppm if desired:

T = Air Temperature — R = Relative Humidity in %

P = Air Pressure — C = Compensation thumbwheel setting, ppm (XXX.X)

$$C = \frac{10^{12}}{N + 10^6} - 999000$$

where N is given in English and Metric systems by:

English (T in degrees Fahrenheit, P in inches of mercury, R in %)

$$N = 9.74443P \times \left[\frac{1 + 10^{-6}\,P\,(26.7 - 0.187T)}{0.934915 + 0.0020388T}\right] - 1.089 \times 10^{-3}\,Re^{0.032015\,T}$$

Metric (T in degrees Celsius, P in millimetres of mercury, R in %)

$$N = 0.3836391P \times \left[\frac{1 + 10^{-6}\,P\,(0.817 - 0.0133T)}{1 + 0.0036610T}\right] - 3.033 \times 10^{-3}\,Re^{0.057627\,T}$$

Table 2. Calculation of Total Compensation

In each case C is then corrected for material temperature with:

$$\text{total } C = C - (TF - 68°F) \times CEF.$$

or

$$\text{total } C = C - (TC - 20°C) \times CEC.$$

where TF or TC = material temperature in °F or °C.
CEF or CEC = material coefficient of expansion in ppm/°F or ppm/°C.

6.3.2 OPERATION UNDER CHANGING TEMPERATURE CONDITIONS. It is very important to realize that material temperature compensation is completely accurate only under constant nonstandard conditions. Relation (4) can be used to compensate for thermal expansion of the part only if the part and the machine are at thermal equilibrium with their surroundings. Changing temperature can result in changing thermal gradients in both the machine and the part. In this case the primary machine errors are due to complex bending effects which distort machine geometry instead of simple thermal expansion. These effects are extremely difficult if not impossible to describe mathematically, and can certainly not be described by relation (4). Bending effects can change the pitch, yaw, straightness, parallelism, and squareness of the machine slideways. The resulting errors are not a function of the positioning transducer used on the machine. Nor are they a function of material temperature. Therefore, if a machine is operated in a poor environment, its accuracy may be limited by its own geometry. In this case, the practical solution is to either improve the environment or make the machine less susceptible to environmental changes. There is no rule-of-thumb which can be used to estimate allowable temperature variation during a machining or measurement cycle to obtain a given tolerance. One can only predict that a given machine will be most accurate when operated in a constant temperature environment. If the machine environment is suspected to be poor it is best to run "drift tests" on the machine to determine environment affects on the machine tolerance.

6.3.3 WHERE TO SENSE MATERIAL TEMPERATURE. Even when a machine is operated at thermal equilibrium in a constant environment, different parts of the machine can be at different temperatures. In order to minimize errors, measure material temperature at a point as close to the workpiece as possible. For example, on a milling machine, if the workpiece is clamped to a table, measure the table temperature since the table is the closest available point to the workpiece. Since the table and the workpiece are in close contact, they will tend to come to the same temperature. Therefore, the table temperature will be indicative of the temperature of the workpiece. On turning machines this may not be possible since the workpiece is held in a rotating spindle. In cases like this, it is necessary to determine empirically which accessible machine member is the closest in temperature to the workpiece.

6.4 Cosine Error

Misalignment of the laser beam path to the axis of motion of the machine tool will result in an error between the measured distance and the actual distance traveled. This is referred to as cosine error because the magnitude of the error is proportional to the cosine of the angle of misalignment.

Cosine error can be visualized as shown in *Figure 31*. The laser beam consists of a number of plane-parallel, equally-spaced wavefronts. The separation between wavefronts is the laser wavelength which is approximately 25 microinches or 0.633 microns. Since the beam diameter is quite large compared to the wavelength, it has been shown large in *Figure 31*.

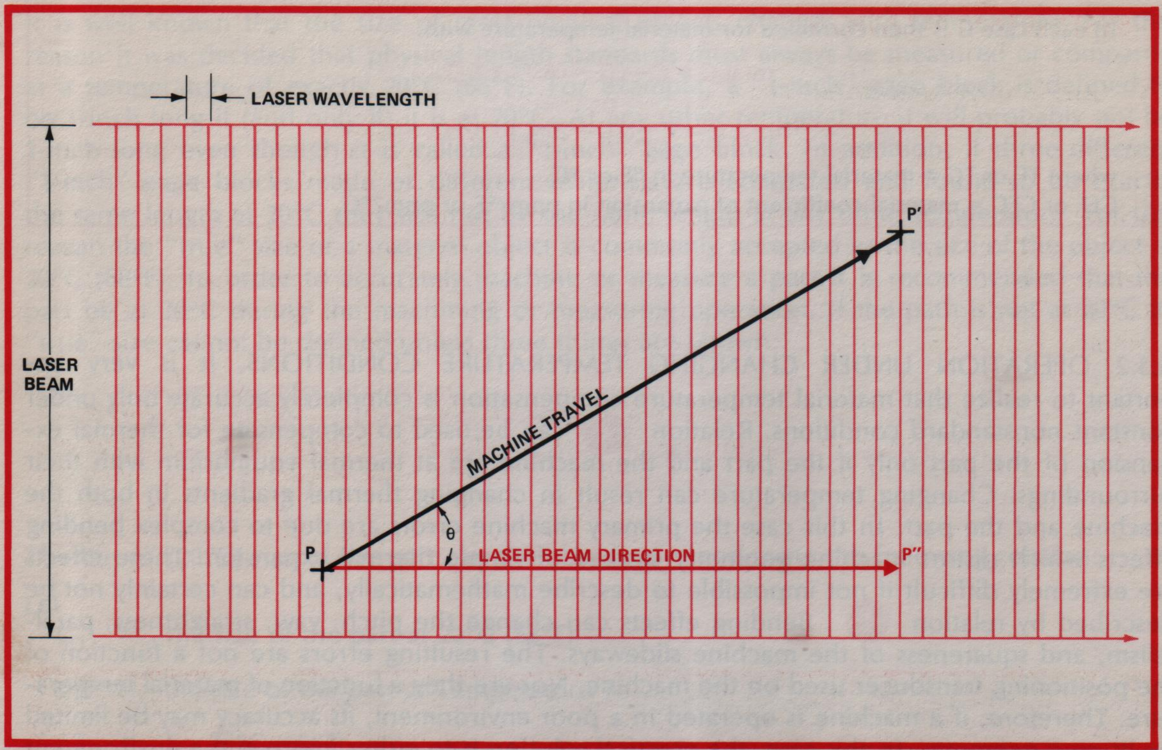


Figure 31. Cosine Error

These wavefronts can be thought of as lines on a conventional scale. As a point on the machine travels along the laser beam, the interferometer counts the number of wavefronts intercepted by the point during its travel. If the point travels along the path P–P′ as shown, the interferometer counts the number of wavefronts intercepted and measures the distance P–P″. In other words the interferometer measures the component of motion in the direction of the laser beam. Since

$$P\text{–}P'' = P\text{–}P' \cos\theta$$

(where θ = angle of misalignment between laser beam and machine axis of motion)

The error in parts per million would be:

$$\text{error} = (1 - \cos\theta) \times 10^6$$

It is obvious from *Figure 31* that the measured P–P″ is shorter than the actual distance traveled P–P′. Note that cosine error always causes the interferometer to read short of the actual distance traveled. *Table 3* shows some typical cosine errors for the angle θ.

Table 3. Angle θ Versus Cosine Error

θ (deg)	θ (rad)	COSINE ERROR
.001	1.7×10^{-5}	1.52×10^{-10}
.01	1.7×10^{-4}	1.52×10^{-8}
.08	1.4×10^{-3}	1.00×10^{-6}
.1	1.7×10^{-3}	1.52×10^{-6}
1	1.7×10^{-2}	1.52×10^{-4}

7 SYSTEM INSTALLATION

7.1 Multiple Measurement Axes

As previously discussed, the Laser Transducer System can measure up to six independent axes of displacement using one 5501A Laser Transducer head. When installing the laser head on a machine of any type, one of the prime considerations is how to direct the laser beam to the point on the machine where the measurement actually takes place. By using the proper combination of beam splitters, beam benders, and interferometers, the measurement axes can be established with a minimum number of components. The following figures illustrate several examples of how the laser beam can be routed for multiaxis measurement configurations.

In *Figure 32* a three-axis measurement configuration is shown with all components aligned in one plane. Note that any of the components (beam benders, beam splitters, or interferometers) could be rotated in increments of 90° to provide a three-dimensional configuration. Since the interferometers can also bend the laser beam through 90°, the number of components used can be minimized. A four-axis measurement configuration is shown in *Figure 33*. Again, any of the components can be rotated in 90° increments to direct the measurement axes into or out of the page.

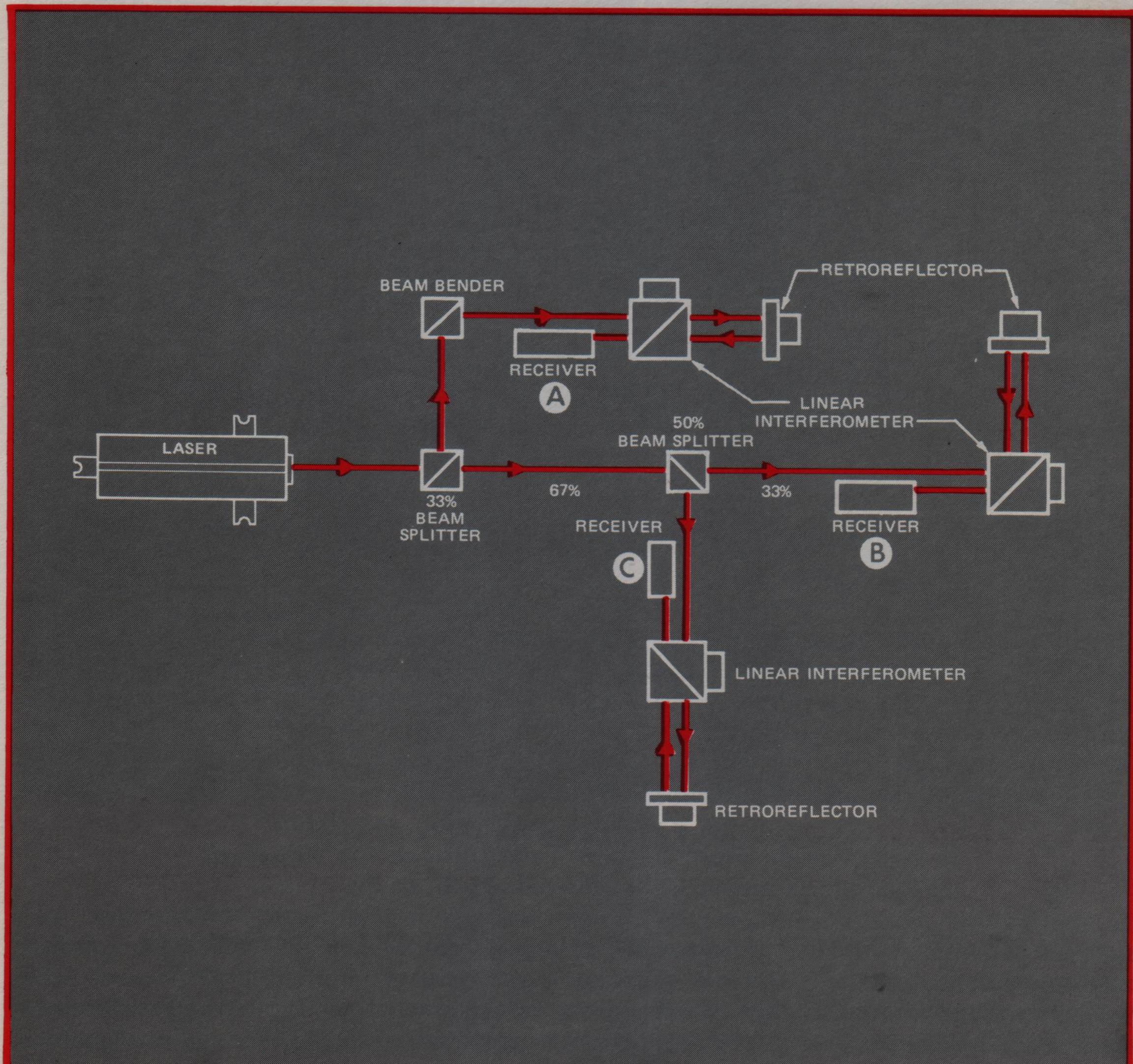


Figure 32. Three-Axis Configuration

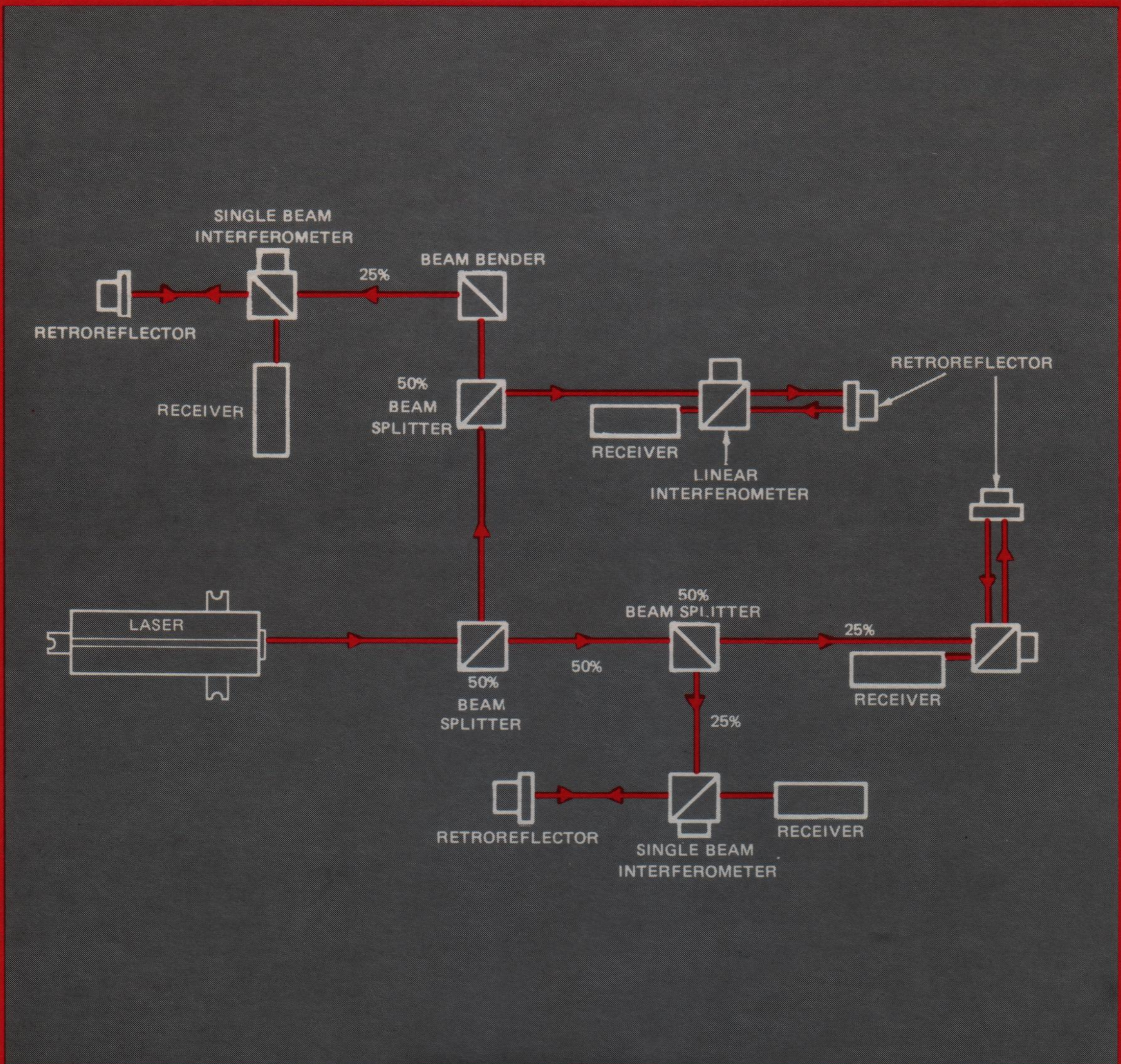


Figure 33. Four-Axis Configuration

NOTE

In a measurement application where the 10702A Linear Interferometer is the moving component and the 10703A Retroreflector is the fixed reference, the 10702A Linear Interferometer must have the Option 001 Windows to eliminate alignment errors. When using the 10705A Single Beam Interferoment along with the 10704A Retroreflector, the interferometer must be the fixed component with **only the retroreflector allowed to move**. For a detailed explanation, see *Figure 11*.
If a right angle beam bend is made through the 10702A or 10705A Interferometers, the above does not apply.

In *Figure 34*, an X–Y stage measurement configuration utilizing the 10706A Plane Mirror Interferometer is illustrated. The X–Y stage has plane mirrors mounted at 90° to each other on the upper portion of the stage which serve as the retroreflectors for the plane mirror interferometer. The advantages of this configuration are discussed later in this section. The 10706A Plane Mirror Interferometer is used to bend the laser beam to the correct orientation.

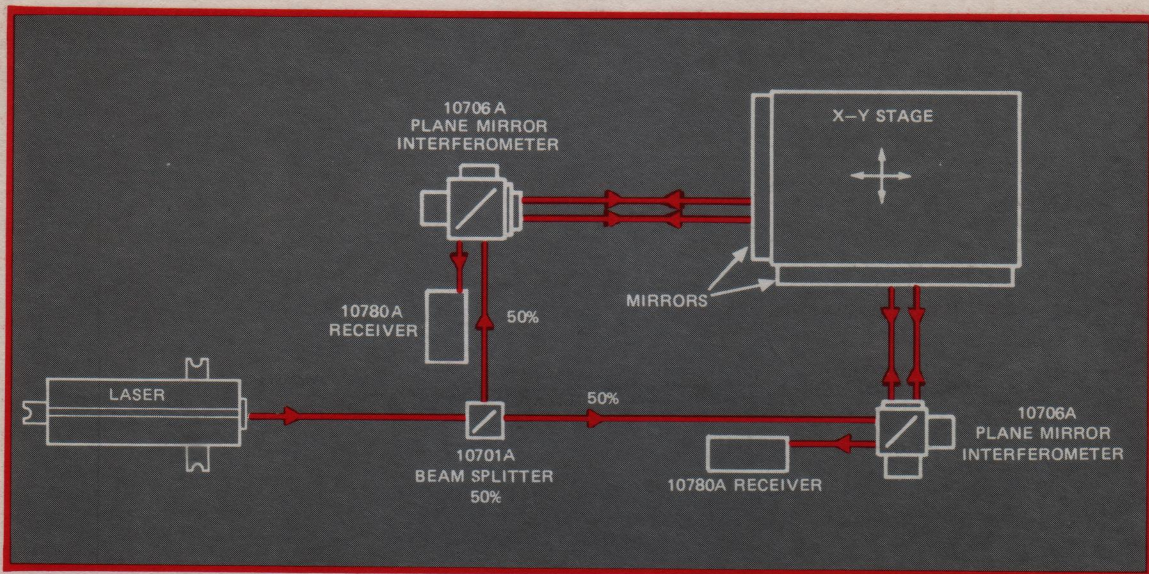


Figure 34. Two-Axis Plane Mirror Interferometer Configuration

In applications where the X–Y stage is installed in a vacuum chamber, the configuration in *Figure 34* may not be suitable. *Figure 35* shows a configuration where the laser beam can enter and exit the vacuum chamber through one window. This allows the receivers to remain outside the chamber and leaves only the optics inside. For window specifications, refer to the paragraph on General Considerations for Mounting Optics.

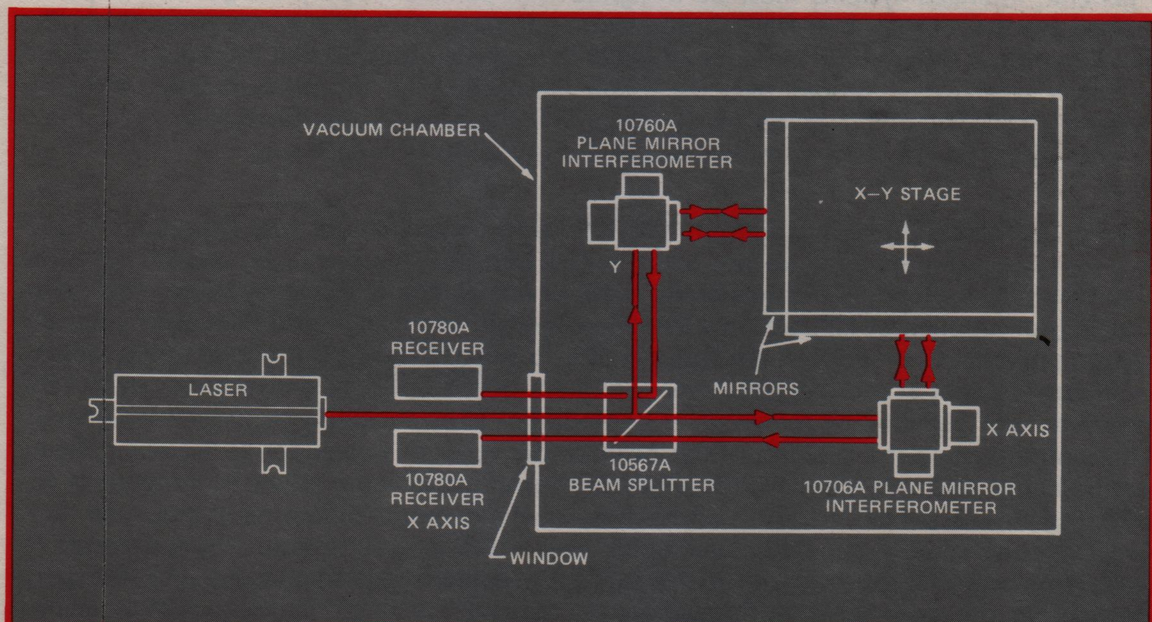


Figure 35. X–Y Stage Installed in a Vacuum Chamber

The configurations depicted above show typical multiaxis measurement applications and assume near equal length measurement paths. When dealing with unequal length measurement paths, consideration must be given to balancing the amount of light in each measurement leg. *Figure 36* shows a measurement configuration in which the distance BD is approximately three times the distance BC. In this case, it is better to use a 33% Beam Splitter than a 50% Beam Splitter even though the system is a two-axis configuration.

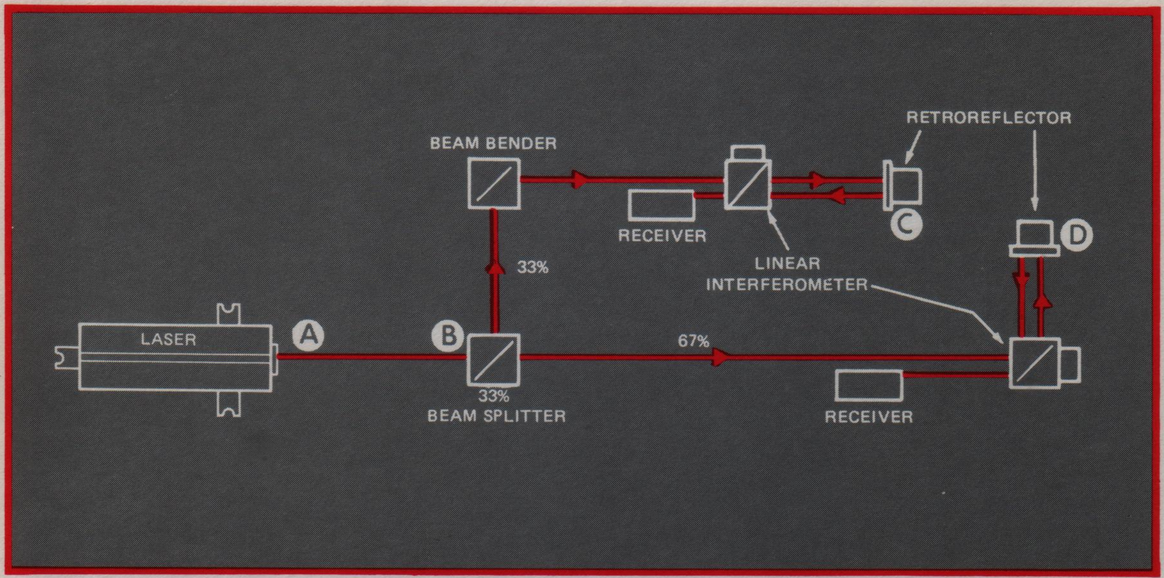


Figure 36.Two-Axis Measurement System with Unequal Measurement Paths

7.2 Beam Path Loss Computation

In general, multiaxis systems must be designed with sufficient safety margin in the power received by the 10780A Receiver. Computation of beam path loss is straightforward. The minimum output power of the laser head is 120 microwatts; most exceed this figure. The output power is relatively constant over the usable life of the tube and tends to drop off slightly toward the end. The minimum necessary power at the receiver is four microwatts. For a three-axis system, the power safety margin is 40 μW ÷ 4 μW or 10:1 on each axis.

Relating this to system configuration, the following considerations are important. Thirty-three percent Beam Splitters are not actually 33% but more on the order of 33% ±5%. The 10700 Series Beam Benders with dielectric coatings reflect 99% of the light. Some other beam benders (not supplied by HP) are only 80–95% reflective, and using more than one causes the losses to multiply. Cube-corners are typically 80% to 90% reflective. Dirt on the optics reduces the amount of light at the receiver. Poor alignment of the optics or the receiver reduces the amount of light detected by the receiver photodiode. This specifically includes misalignment of the optics causing the position of the beam at the receiver to wander as the object being measured runs down its travel. Fluctuations of the refractive index of air in the path of the interfering beams (which can be caused by local temperature differences) cause the laser beam to lose some of its coherence and could even break it for an instant. This is detected by the electronics which causes an error signal to be generated. The smaller the received signal safety margin, the more likely the fluctuations are to break the beam. Techniques of protecting the laser beam to minimize these fluctuations are discussed later in this section.

One thing that must be kept in mind when calculating the path loss in an axis of the laser is that the optics split the two frequency components of the laser beam into two separate paths for each axis and the losses are normally computed separately for each of the two components. Since the laser beam is detected by a mixing process and the result is proportional to the product of the power of the two frequencies, the loss bookkeeping can be handled by calculating a transmission factor for each path. The overall transmission factor is then the product of all the individual transmission factors. (The transmission factors refer to *usable signal* transmitted and *not* to light intensity.)

The minimum power at the receiver must be four microwatts, and the guaranteed minimum power out of the laser is 120 microwatts, so the minimum allowable transmission factor is $(4/120)^2$ = 0.0011. Some typical transmission factors for transducer optical modules are as follows (these are worst-case numbers, which must be used for loss computation):

10700A	33% Beam Splitter 33% Side	0.08
10700A	33% Beam Splitter 67% Side	0.38
10701A	50% Beam Splitter each Side	0.19
10702A	Linear Interferometer†	1.00
10703A	Retroreflector	0.80
10704A	Retroreflector	0.80
10705A	Single-Beam Interferometer†	0.85
10707A	Beam Bender	1.00
10706A	Plane Mirror Interferometer*	0.54
10567A	Beam Splitter	0.19

†*This refers to the beam splitter only. The attached retroreflector must be considered as a separate component. (See example below)*

**The plane mirror interferometer is listed as 10706A. This, however, consists of a plane mirror converter, a 10702A and two 10703A's. The transmission factor for this device would therefore be 1 X 0.8 X 0.8 X 0.85 = 0.54.*

As an example, consider a typical installation with three axes (see *Figure 32*). Assume linear interferometers on each axes, good optical alignment, and comparable path lengths. Assume that the three axes have the following components:

Axis A:	10700A (33%), 10707A, 10702A, 10703A (2)
Axis B:	10700A (67%), 10701A, 10702A, 10703A (2)
Axis C:	10700A (67%), 10701A, 10702A, 10703A (2)

The transmission factors are, for each axis:

Axis A:	(0.08) x (1.00) x (1.00) x (0.80) x (0.80) = 0.0512
Axis B:	(0.38) x (0.19) x (1.00) x (0.80) x (0.80) = 0.0462
Axis C:	(0.38) x (0.19) X (1.00) x (0.80) x (0.80) = 0.0462

Here, B and C are worst-case (net product is smallest) but still have a transmission factor 42 times greater than 0.0011. Therefore, these axes can operate with an additional transmission factor caused by dirt, misalignment, etc., of up to 1/42=0.024. (Note that the worst-case numbers for the beam splitters take into account the power division along each measurement axis.)

7.3 Installation Examples

The following examples illustrate the installation of a 5501A Laser Transducer System on a three-axis machine tool (*Figure 37*) and a three-axis measuring machine (*Figure 38*).

The three-axis machine tool installation (*Figure 37*) includes the 10702A Linear Interferometer and the 10703A Retroreflector. These measurement components were chosen because they are the least expensive and meet all measurement requirements.

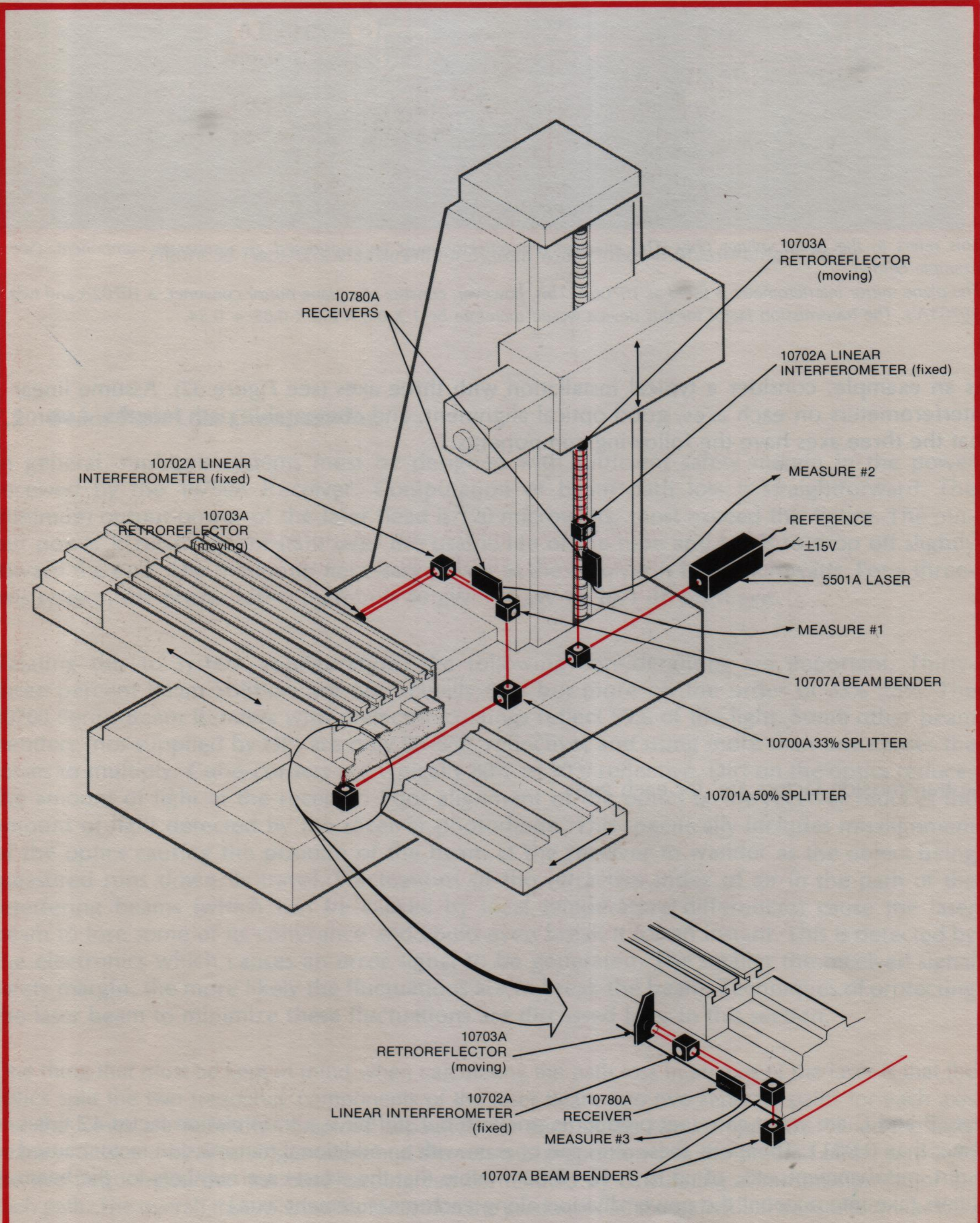


Figure 37. Three-Axis Machine Tool Installation

The three-axis measuring machine installation (*Figure 38*) includes the 10705A Single Beam Interferometer and the 10704A Retroreflector. These measurement components were chosen to eliminate any loss of travel because of limited space considerations. It was determined that the optimum installation position for the 5501A Laser Transducer head was at the top of the machine to minimize the optical path lengths.

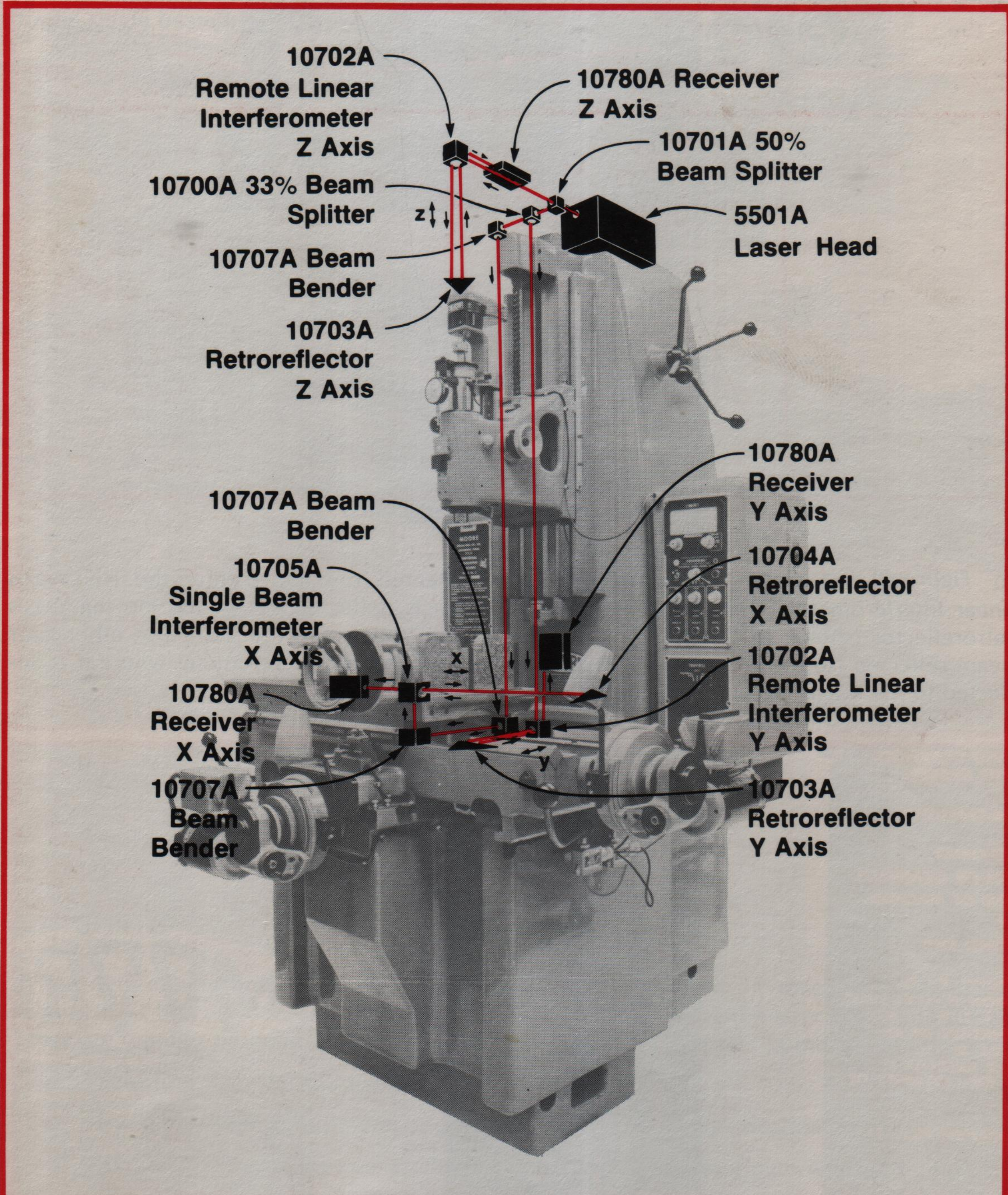


Figure 38. Three-Axis Measuring Machine Installation

Figure 39 shows the laser head installed on the top of the measuring machine on a single mounting plate (this approach simplifies and speeds the alignment procedure). The portion of the laser beam reflected by the first beam splitter is sent to a second beam splitter. The laser beam is again split into two portions. One portion is directed to the Y-optics and the other (using a beam bender) is directed to the X-optics.

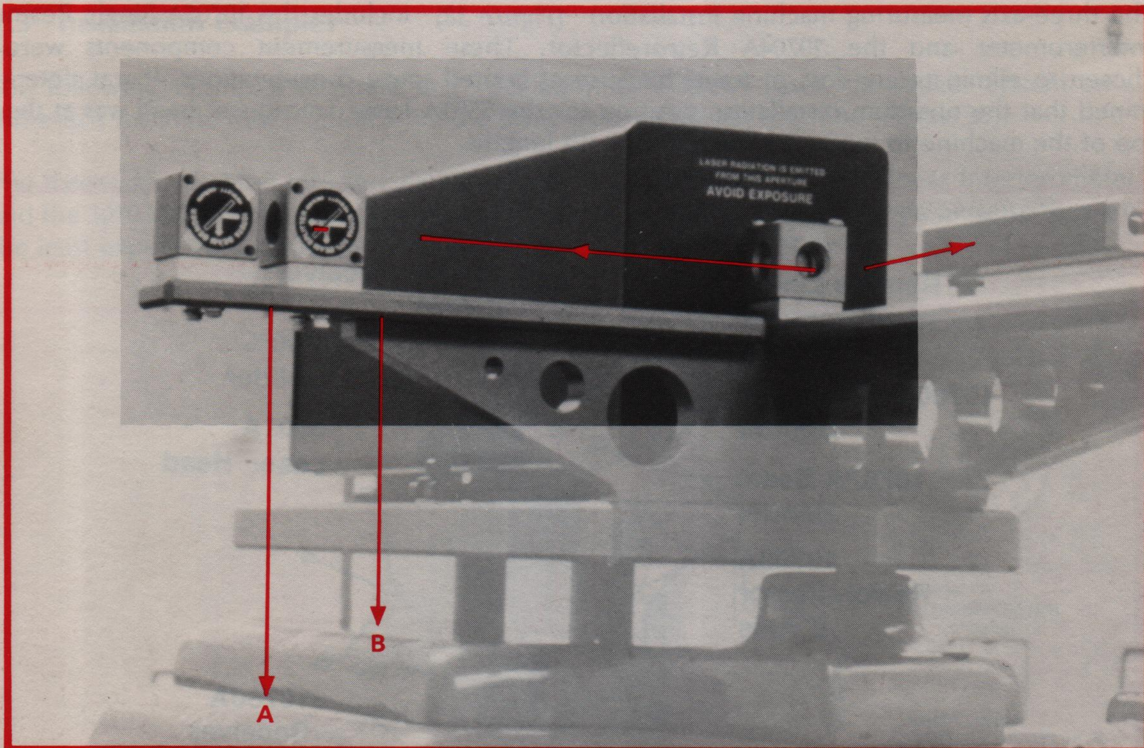


Figure 39. Laser Head Installation

In *Figure 40* one of the two parallel light beams reflected from above enters the fixed Y-axis linear interferometer. There the measurement beam is deflected 90° to the moving Y-axis retroreflector (shown in *Figure 41*) attached to the Y-axis machine slide. The other laser beam reflected from above enters a beam bender next to the interferometer where it is deflected to the X-axis measurement optics.

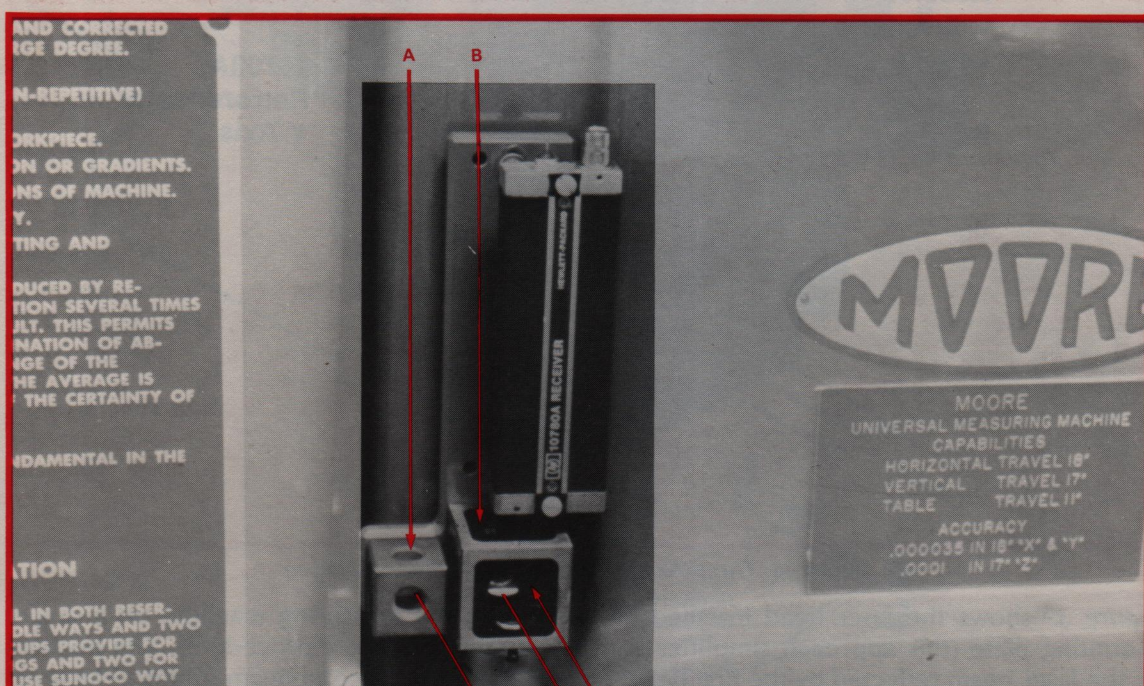


Figure 40. Y-Axis Installation

Figure 41 shows the Y-axis retroreflector and the X-axis measurement optics. All of the optics are mounted on a common bracket which is attached to the Y-axis. The laser beam reflected from the beam bender in *Figure 40* enters the beam bender shown below the single beam interferometer and is reflected vertically into the single beam interferometer. The measurement beam is then reflected horizontally along the X-axis to a retroreflector attached to the X-axis machine slide (not shown). Note the position of the X-axis receiver which is unique to the single beam interferometer.

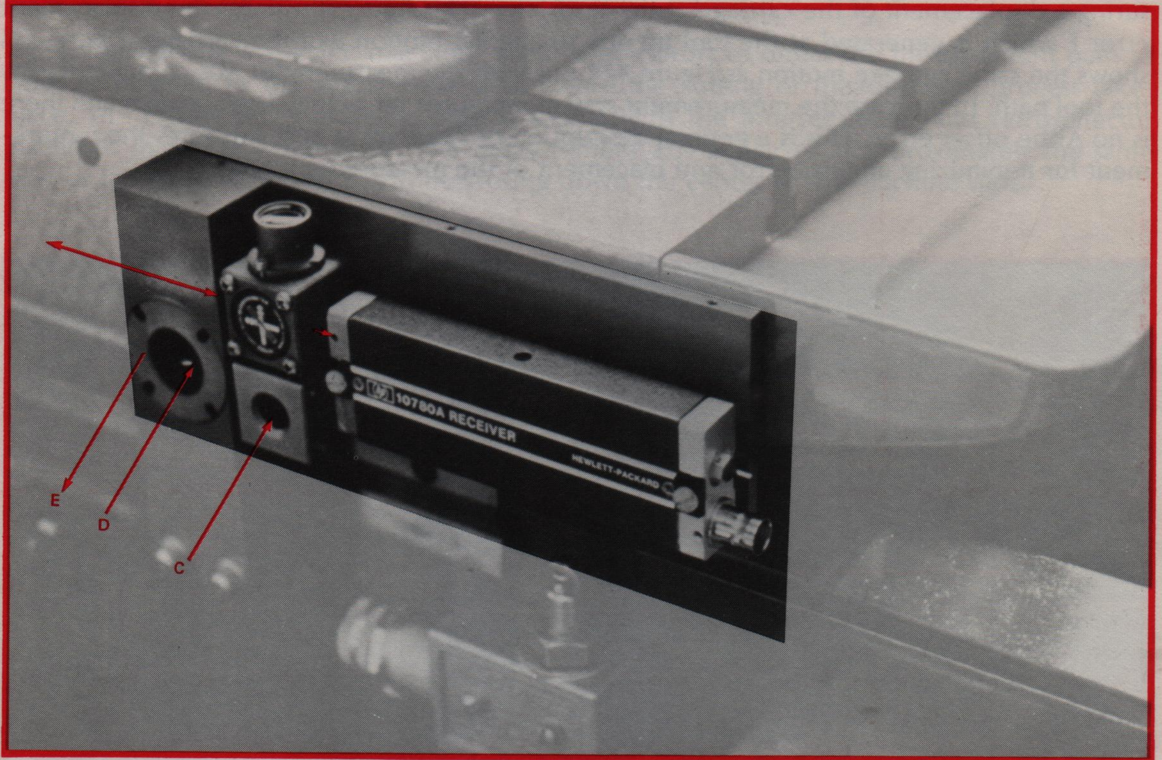


Figure 41. X-Axis Installation

8 MECHANICAL INSTALLATION CONSIDERATIONS

8.1 General

When determining how to install the Laser Transducer on a specific machine, a number of factors must be considered in addition to the method of dividing the laser beam into the appropriate number of measurement axis. Some of the more important points to consider are:

a. Selecting the measurement paths to minimize Abbe error.

b. Installing the interferometer and retroreflector to minimize deadpath errors.

c. Avoiding extreme thermal gradients near the measurement path which could disrupt the measurement or cause errors.

d. Providing protection for the laser beam where cutting fluid, chips, or air turbulance could interfere with the measurement.

In many cases it may not be possible to completely eliminate these sources of error but every effort should be made to minimize them. The following paragraphs discuss methods of installing the Laser Transducer System that maximize accuracy and measurement reliability.

8.2 Abbe Error

A very important advantage of the Laser Transducer System is that the Abbe error evident in almost all positioning systems is very easily reduced. Abbe error occurs when a displacement measurement is taken at a location which is offset from the displacement to be measured and the slideways which provide the displacement exhibit angular motion.

In *Figure 42A*, the measurement axis is coincident with the leadscrew centerline and is measuring a displacement of the carriage at the leadscrew. This figure illustrates the displacement error E which is generated at the tool tip due to angular motion θ of the carriage. *Figure 42B* shows the same carriage motion as *Figure 42A* but with the measurement axis coincident with the tool path. In this case the measurement system measures the actual displacement and there is no Abbe offset error. This is a general description of Abbe error and illustrates the requirement for minimizing angular error and placement of the measurement path.

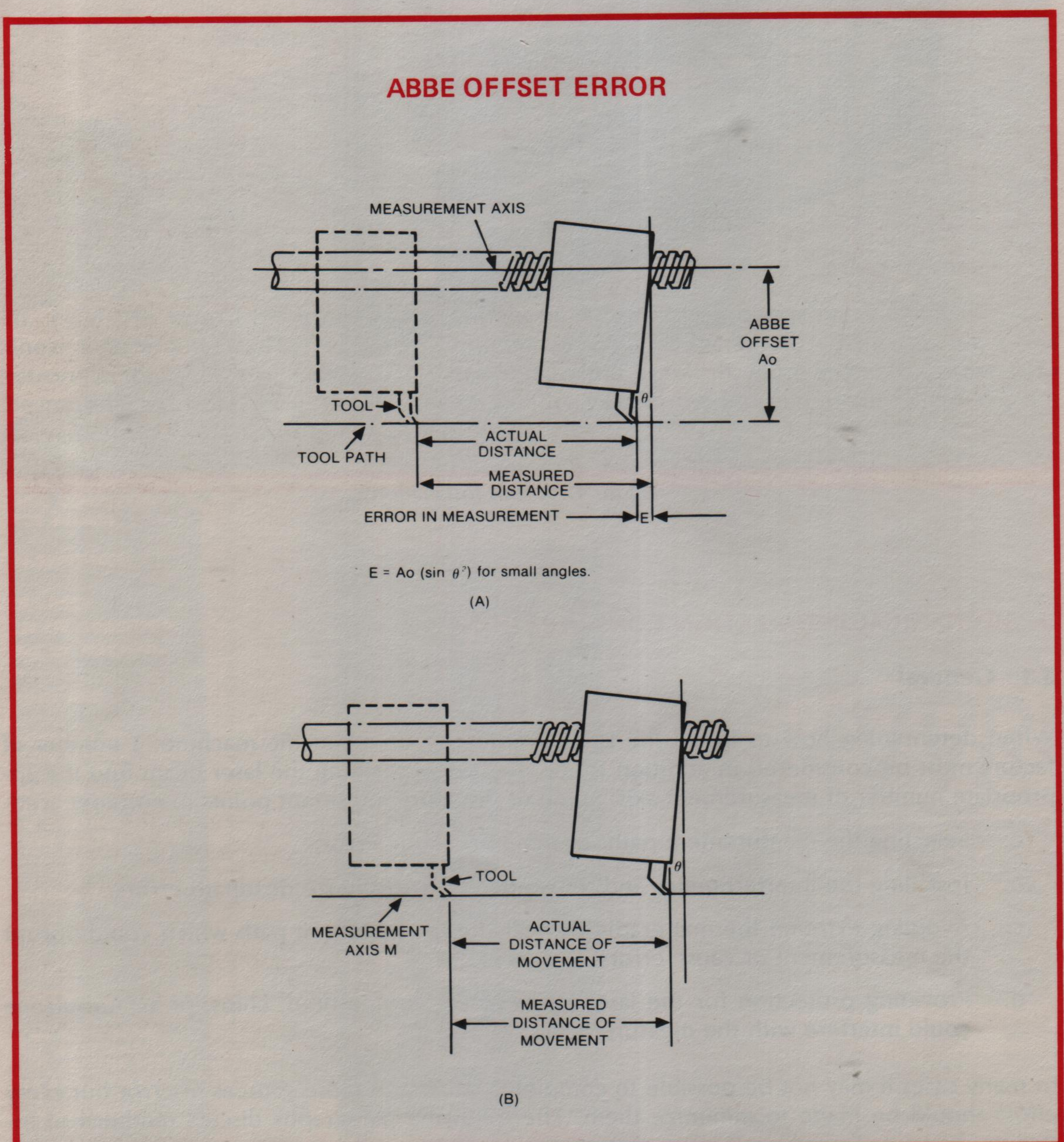


Figure 42. Abbe Offset Error

NOTE

A rule of thumb which is helpful for approximating the error attributable to angular motion is that for each arcsecond of angular motion, the error introduced is approximately 0.1 microns per 20 mm of offset (5 microinches per inch of offset).

When considering a specific machine, make every effort to direct the measurement path as close as possible to the actual work area where the cutting or measurement process takes place. In *Figure 43* a machine slide is shown with the interferometer and retroreflector placed to minimize Abbe error. The measurement axis is placed at approximately the same level as the work table and is also measuring down the center of the machine slide.

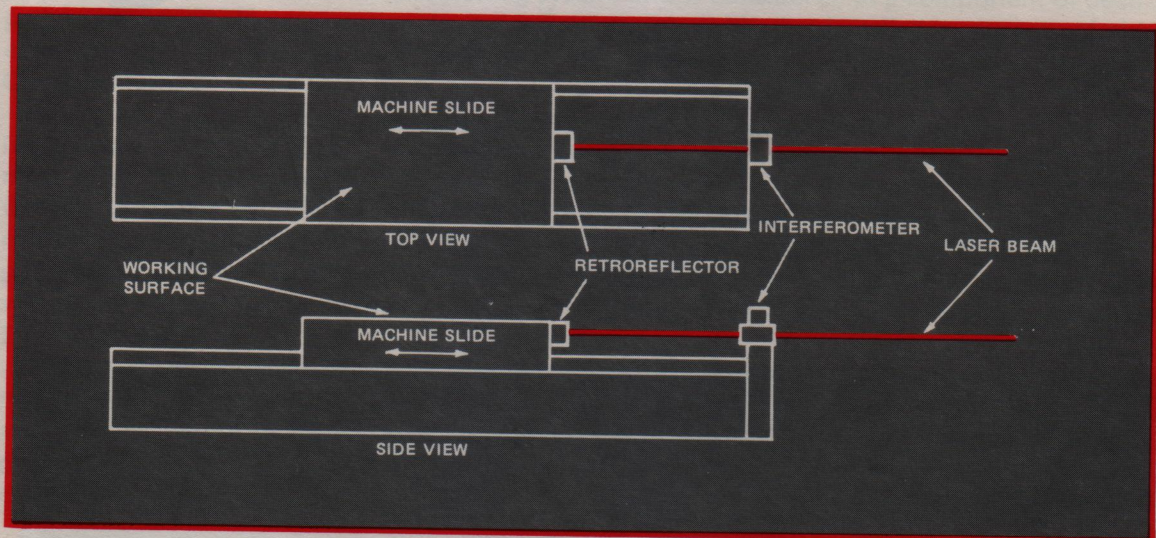


Figure 43.Positioning of Measurement Axis to Minimize Abbe Error

Although compromises must often be made because of mechanical interference or inaccessibility, the closer the measurement path of the Laser Transducer System is placed to the working surface, the smaller the measurement error is due to geometric inaccuracies of the machine.

With machines that exhibit small geometric errors, it may be adequate to mount the interferometer on the side of the machine slide and below the work surface without significantly affecting the measuring or cutting accuracy.

A special case where the Laser Transducer System can make a significant contribution to minimizing Abbe error is on high precision X-Y stages. Using the 10706A Plane Mirror Interferometer in conjunction with plane mirrors, mounted at 90° to each other on the top edges of the X-Y stage, a very accurate positioning system which almost completely eliminates Abbe error is achieved. *Figure 44* shows a typical installation for an X-Y stage. The principal advantage of this type of positioning system is that the measurement in both X and Y axes takes place at the work surface. If there are angular errors in the cross slides of the stage, any displacement of the work surface due to these errors is measured by the Laser Transducer System.

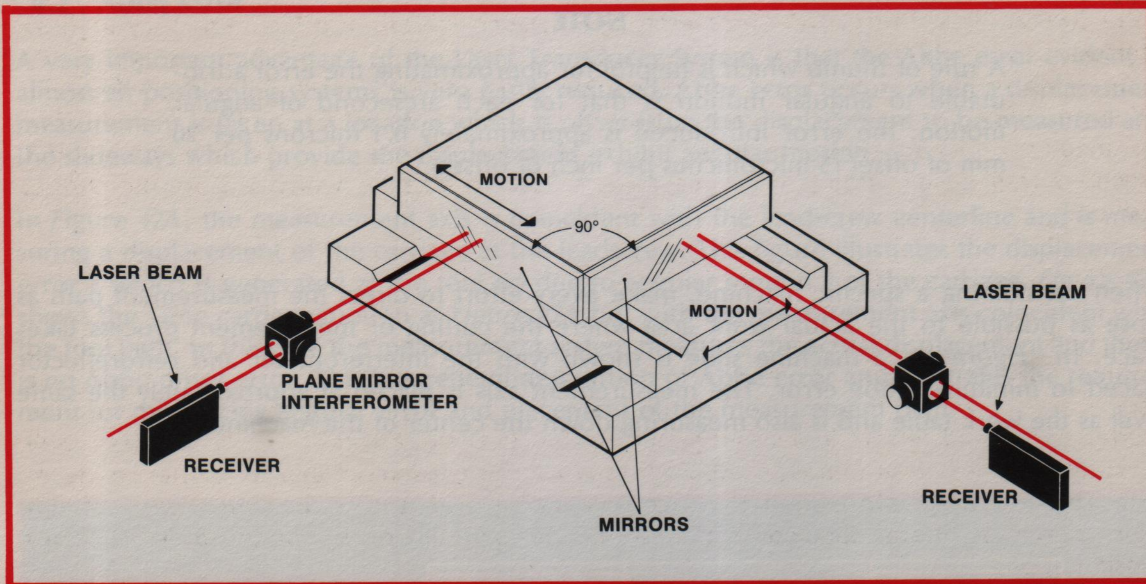


Figure 44. X–Y Stage Measurement with 10706A Plane Mirror Interferometer

In addition, if the mirrors are aligned at exactly 90° to each other, the orthogonality of the positioning system is determined by the mirrors and not the X-Y slides. *Figure 45* illustrates the actual measurement which takes place if there are any geometric errors in the X-Y stage.

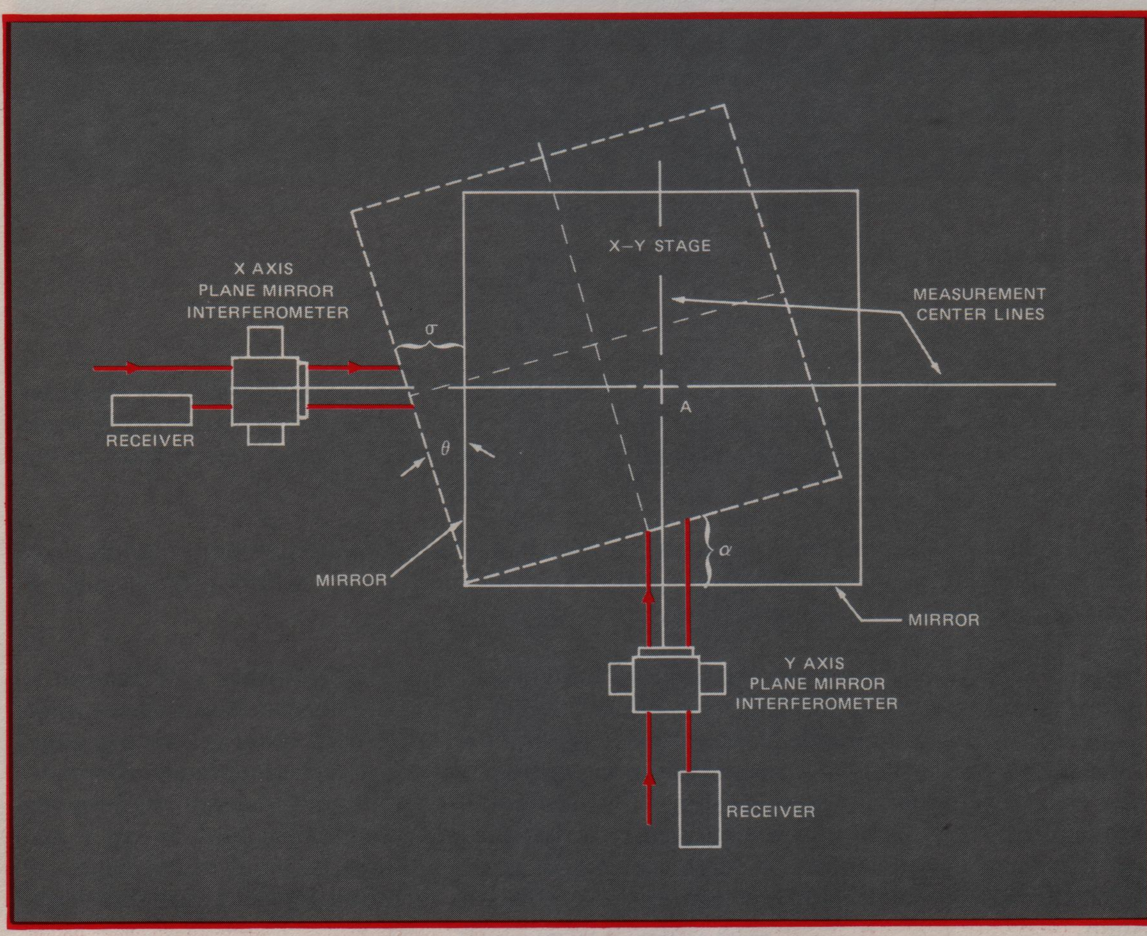


Figure 45. X–Y Stage Geometric Errors

If the 10706A Plane Mirror Interferometers are installed with their measurement centerlines intersecting on the axis of the fixed cutting tool, measuring probe, lens centerline, etc., (Point A), then X-Y position errors due to any yaw angle errors can be corrected. For example, if the X-Y stage undergoes an angular error θ, then the point of interest A is displaced to A′. Since this angular error also generates an X- and Y-axis position error of σ and α in the X and Y directions respectively, point A′ can be moved back to point A which will be the correct position.

8.3 Deadpath Errors

When installing any displacement transducer in a positioning system, temperature effects causing thermal expansion of the system can be a significant source of error. When using the Laser Transducer System as a displacement measuring device, proper positioning of the interferometer and retroreflector can minimize this source of error. The error manifests itself primarily as a zero offset in the positioning system and is considered as a component of deadpath. The following information is concerned mainly with the installation aspects of this error source. A more detailed discussion of deadpath error is contained in Accuracy Considerations.

In general, when installing the interferometer and retroreflectors in a positioning system, make every effort to ensure that these components are almost in contact physically when the machine is at its coordinate system zero point. In *Figure 46* the interferometer and retroreflector are installed with the distance AB at a minimum when the saddle is at its closest point of travel to the machine table. In addition, place the fixed component of the measuring system (interferometer or retroreflector) as close as possible to the machine reference system. This helps compensate for thermal expansion.

If, because of interference or inaccessiblility, it is not possible to mount the interferometer and retroreflector in close proximity to each other, provision is made to compensate for this problem. The compensation is made in the interface electronics in conjunction with the controller.

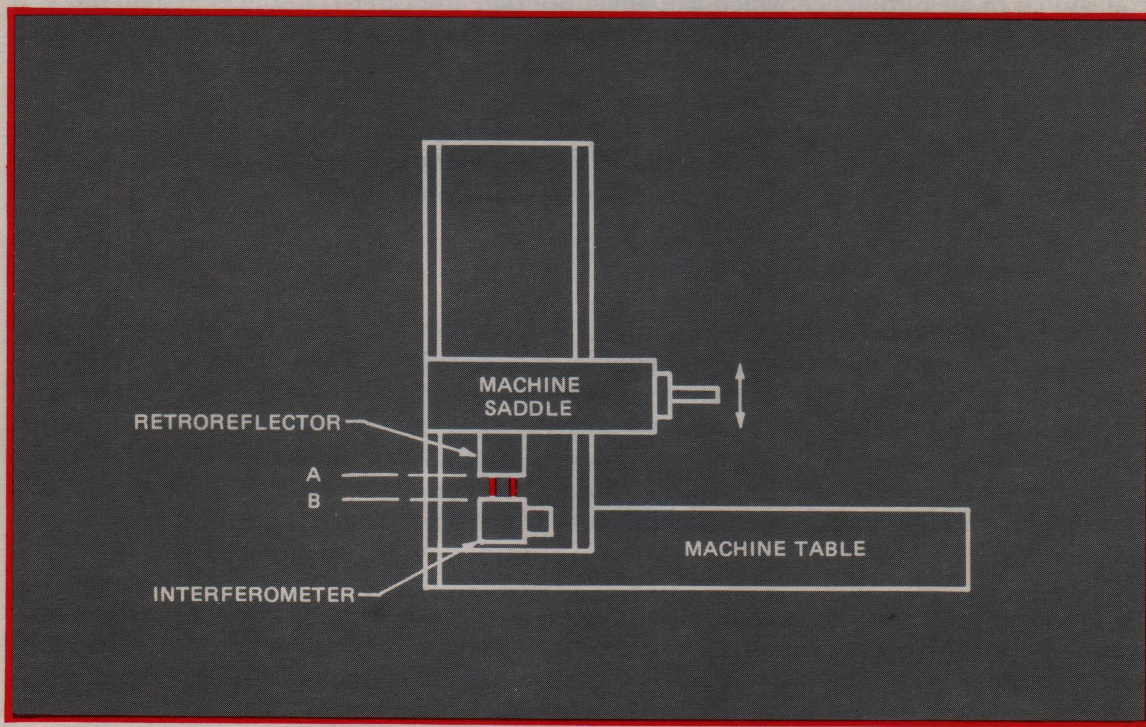


Figure 46. Installation of Optics for Minimum Deadpath

8.4 Air Turbulence

One of the most important factors to be considered during the installation of the Laser Transducer System is air turbulence. Air turbulence, or inhomogeneity of the air in the optical measuring path, is usually caused by variations in air temperature. The major effect of air turbulence is to reduce the amount of signal at the receiver. This reduction is due to either a physical deflection of the laser beam or a degradation of the coherence of the beam. If the air turbulence conditions become excessive, this could result in a complete loss of measurement signal. This loss of signal is detected by the interface electronics.

In uncontrolled environments such as a machine shop, the effects of air turbulence can be minimized by protecting the laser beam with covers of some type. Since this will undoubtedly be done anyway for protection against beam breakage caused by cutting fluid or metal chips, air turbulence effects will usually not be a significant installation factor in typical shop environments.

One application where serious consideration must be given to air turbulence is in temperature controlled environments. Although it would appear that such an environment would be ideal, temperature controlled areas often exhibit greater air turbulence than non-controlled areas. This turbulence is caused by a non-uniform air temperature resulting from the mixing of new air from the temperature control unit with existing air. Since air is a poor heat conductor, any attempt to change the temperature of the environment by heating and cooling the air causes non-uniform air temperature. On a long term basis, this provides good measurement conditions regarding thermal expansion effects. However, the short term fluctuations can cause measurement signal degradation in the Laser Transducer System.

Protection against air turbulence problems which occur in controlled environments depend largely on the specific application. For systems such as integrated circuit photomask cameras in small closely controlled rooms, it may be sufficient to provide constant air flow over the measurement paths. In other cases, such as measuring machines, protecting the laser beams with covers prevents air turbulence effects from interfering with the measurement.

One source of air turbulence which can affect not only the Laser Transducer System but also the accuracy of the machine itself is localized heat sources (e.g., motors, pumps, etc.) located on or near the machine. Make every effort to shield the measurement path from these types of heat sources. Note that a local heat source which can affect the Laser Transducer System enough to cause measurement signal loss also tends to degrade the geometric accuracy of the machine through warping or bending. Therefore, consideration should be given to thermally isolating the heat source from the machine as well as the measurement path.

8.5 Laser Beam and Optics Protection

In almost all positioning systems, some type of protection is generally provided for the protection of the displacement transducer whether it is a leadscrew, glass scale, or Laser Transducer System. This prevents metal chips or cutting fluid from interfering with the measurements. In the case of the Laser Transducer System, it can also provide additional protection against unintentional laser beam blockage and air turbulence problems. In addition, the optical components usually require protection to prevent contamination of the optical surfaces by oil or cutting fluid. In many applications which are "clean", no protection at all may be needed.

If protection of the laser beam and optical components is required, there are two general types; moving component protection and non-moving component protection. Since the 5501A Laser Transducer and 10780A Receiver are housed in NEMA-12 type enclosures, no protection for these devices is needed except in the most severe environments.

In many applications where the Laser Transducer is installed, the only moving components are the interferometer and retroreflector. Many of the beam splitters and beam benders are mounted in a stationary manner and only direct the laser beam to the measurement axes. In these cases it is only necessary to provide fixed tubing for the laser beam and some type of sealed enclosures for the optics. Since only one laser beam of approximately 7 mm (0.3 inch) is involved, relatively small diameter tubing can be used. Electric cable conduit for the laser beam and electrical junction boxes have proved successful for this type of protection.

Since either the interferometer or the retroreflector is moved during the measurement, protecting the laser beam and the moving components requires some type of telescoping cover or a cover of the type that is self-sealing. There are a wide variety of commercially available protective covers which are suitable for this purpose.

Figure 47 illustrates techniques for protecting the laser beam and optical components with different types of protective covering. Note that the cover for the retroreflector allows the retroreflector to be moved very close to the interferometer. This helps minimize the deadpath errors previously discussed.

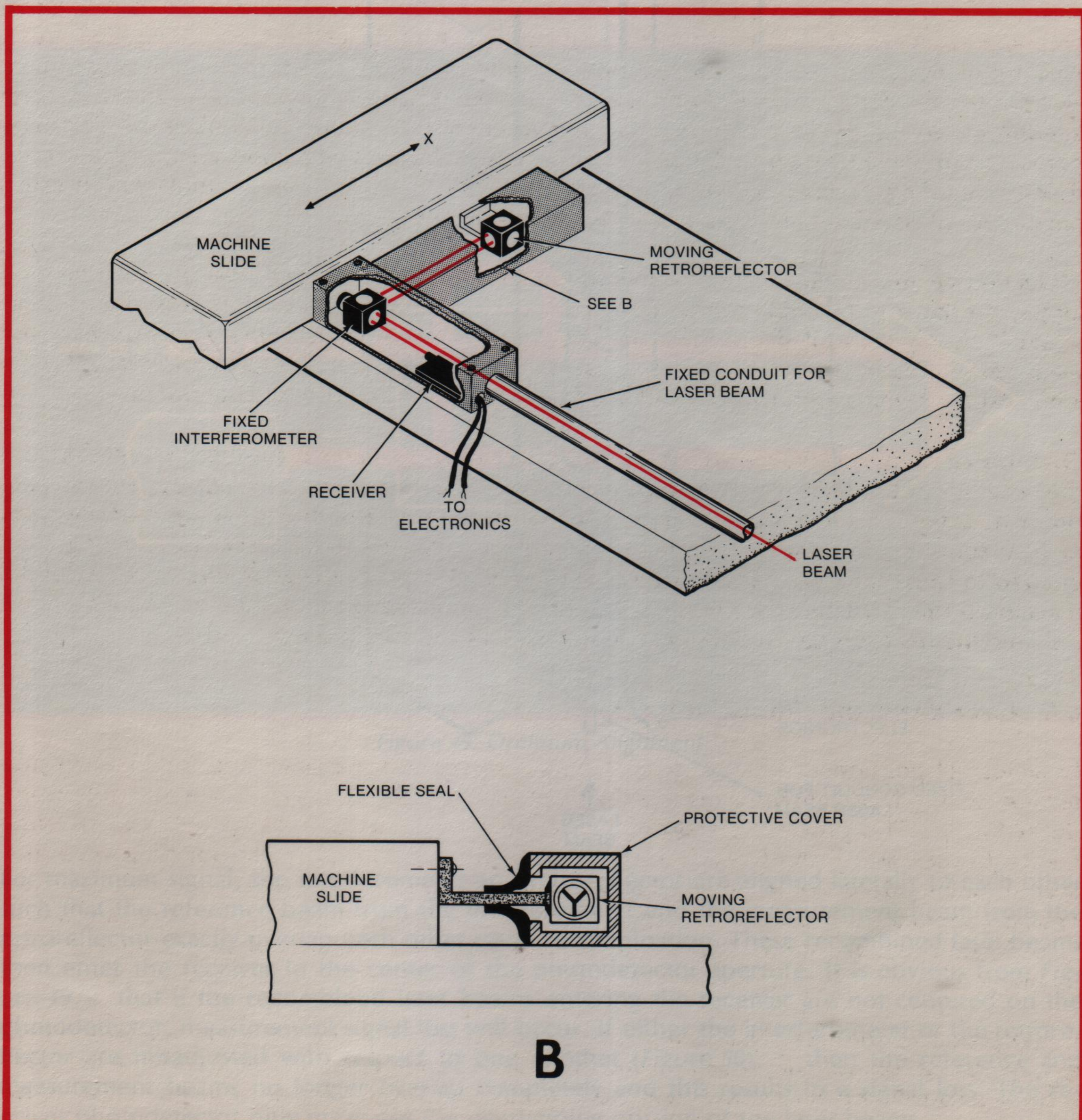


Figure 47. Protective Covers for Optics and Laser Beam

Figure 48 shows a different type of protective cover. Again, the mechanical arrangement allows the retroreflector to be in close proximity to the interferometer at the closest point of travel even though the telescoping cover is not entirely collapsible.

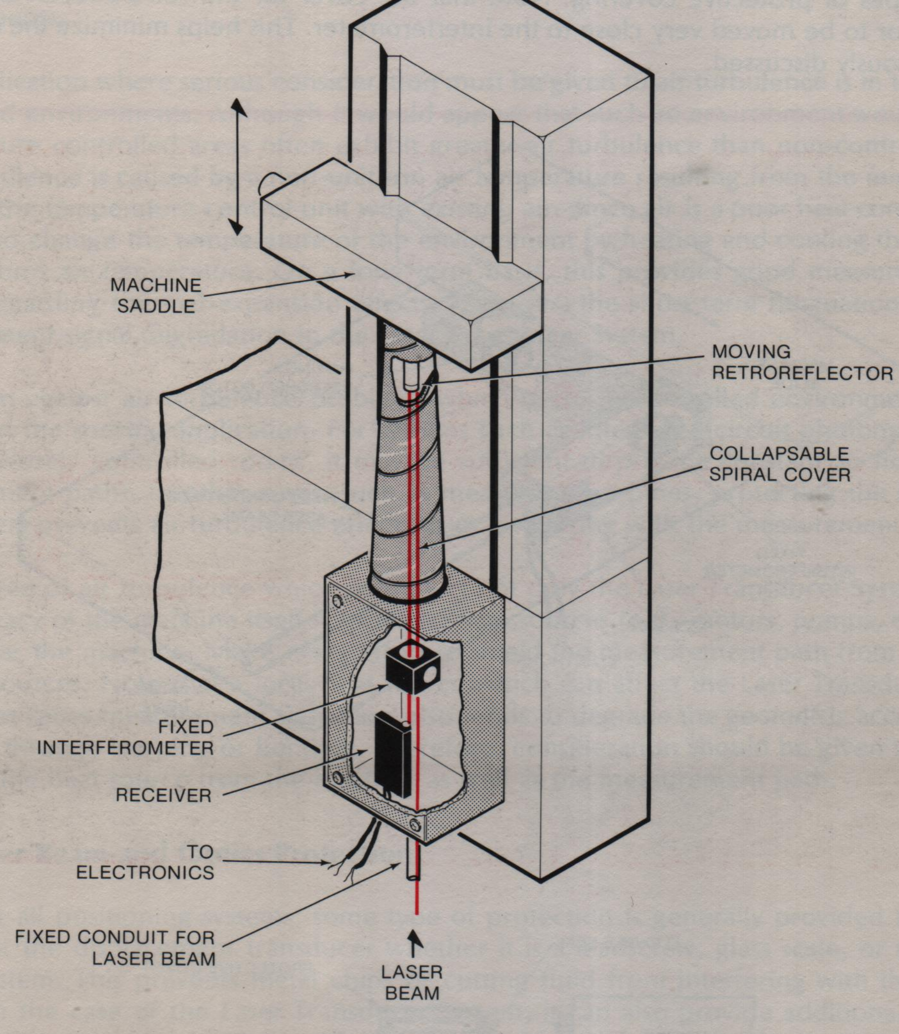


Figure 48. Collapsilbe Spiral Cover for Movable Retroreflector

9 ALIGNMENT PROCEDURES

9.1 General

When installing any displacement transducer in a positioning system, the transducer must be aligned to ensure correct operation and minimum measurement error. The two major objectives in aligning the Laser Transducer System are to maximize the measurement signal at the receiver to ensure reliable operation and to minimize cosine error. These objectives are generally accomplished simultaneously during the alignment process. Each measurement axis should be analyzed separately depending on the type of interferometer used and its relationship to the entire measurement system.

In general, the laser beam in the measurement is required to be parallel to the motion of travel to minimize cosine error and the optical components and receiver are required to have a specific spatial relationship to maximize the measurement signal. *Figure 49* shows a measurement axis where the laser beam is parallel to the mechanical motion of travel of the retroreflector and is optimized for maximum measurement signal.

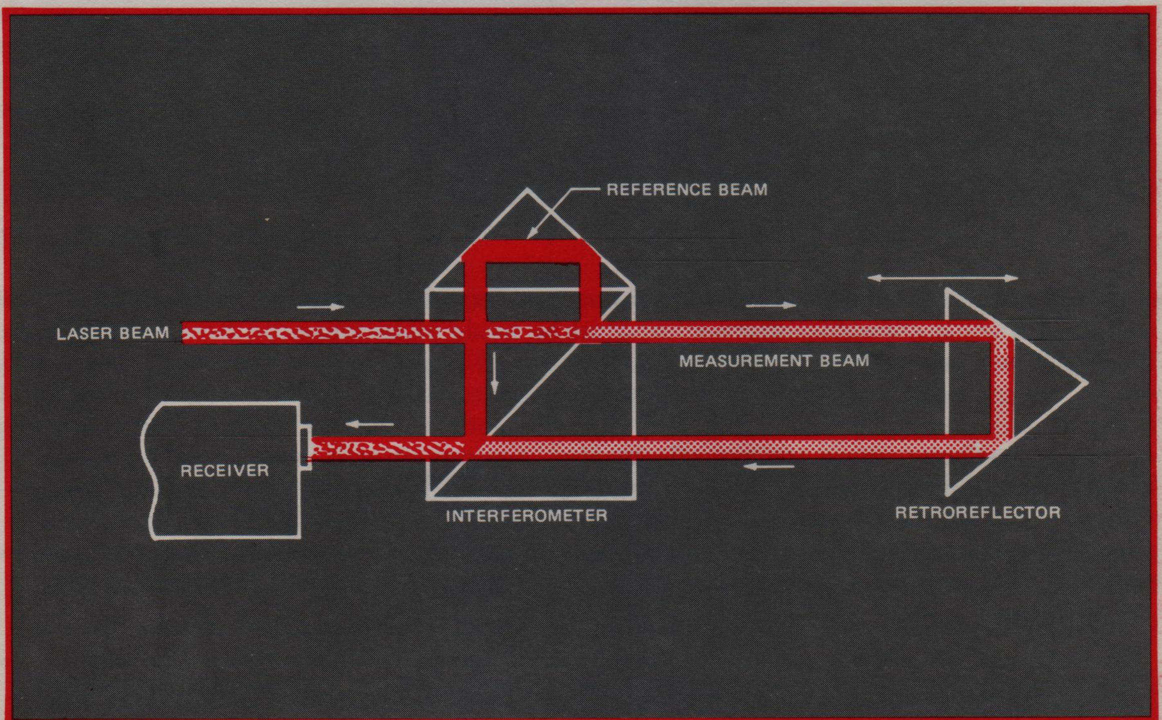


Figure 49. Optimum Alignment

For maximum signal, the interferometer and retroreflector are aligned laterally to each other such that the reference beam from the interferometer and the measurement beam from the retroreflector exactly overlap each other upon recombination. These recombined laser beams then enter the receiver in the center of the photodetector aperture. It is obvious from *Figure 49*, that if the recombined laser beams entering the receiver are not centered on the photodetector, measurement signal loss will occur. If either the interferometer or the retroreflector are misadjusted with respect to one another (*Figure 50*), then the reference and measurement beams no longer overlap completely and this results in a signal loss. The receiver photodetector only measures the overlapping portion of the laser beams.

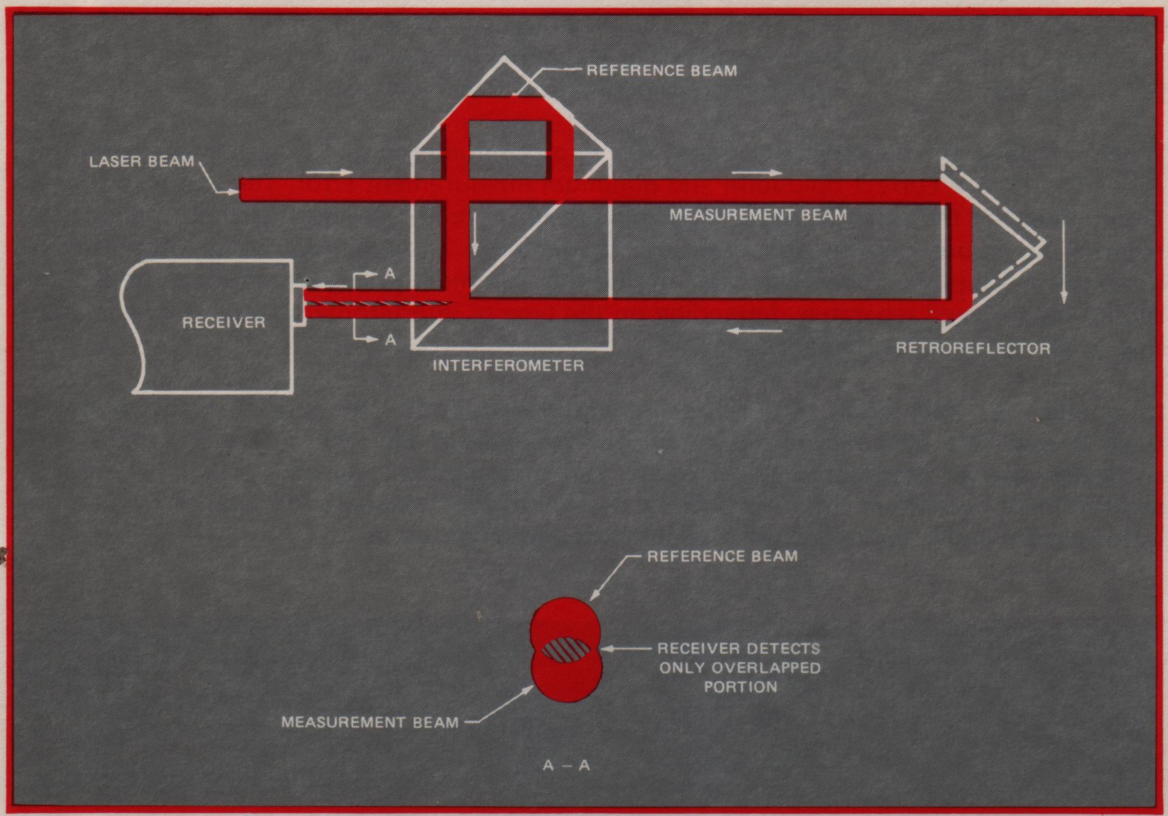


Figure 50. Effect of Optics Misalignment

A lateral offset of the interferometer has the same effect. Although a maximum offset of ±2.5 mm (±0.1 inch) is allowable, every effort must be made to optimize the laser beam overlap for maximum performance.

If the measurement beam is not angularly aligned parallel to the mechanical motion of travel of the retroreflector, there are two effects. First, a cosine error is included in the measurement of a magnitude directly related to the angle of misalignment. (For a complete description of cosine error refer to Accuracy Considerations.) Second, the angular misalignment also causes a displacement of the measurement beam with respect to the reference beam at recombination. This results in additional signal loss. *Figure 51* illustrates the result of angular misalignment.

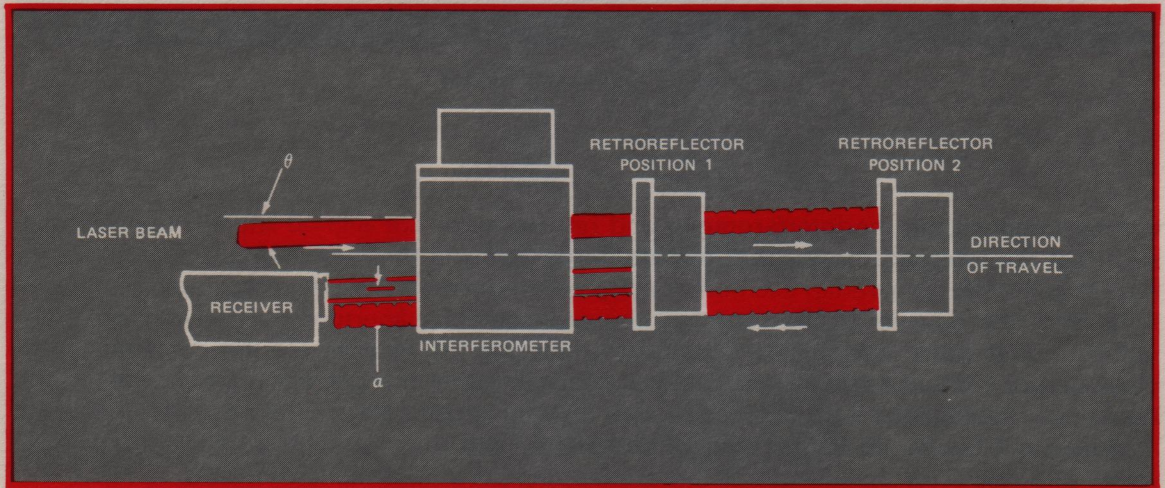


Figure 51. Effects of Angular Misalignment to the Direction of Travel

The cosine error is purely a function of the angle θ and the displacement α of the return measurement beam is a function of the angle θ and the distance traveled. In addition, a cube-corner retroreflector such as the 10703A or 10704A has the property of doubling the displacement of the laser beam (i.e., if the incoming laser beam to the retroreflector displaces 1 mm, the total separation between the incoming and outgoing beam is increased by 2 mm). Over short travel it is possible to maintain measurement signal even though there is considerable cosine error.

NOTE

> The presence of measurement signal through the total length of travel does not guarantee that the measurement axis is aligned for minimum cosine error. Also, any angular misalignment of the laser beam to the direction of travel causes a decrease in the measurement signal.

10 ALIGNMENT TECHNIQUES

There are two basic alignment techniques used with the Laser Transducer System: Visual alignment, which is a very satisfactory method in applications involving relatively long travel; and autoreflection, which is used for short travel applications and measurements where cosine error must be reduced to the absolute minimum possible. In general, regardless of the techniques used, alignments are performed with all optical components in place, **and since the alignment procedures require adjustment of the optical components, provisions must be made for this when the components are installed on the machine.**

10.1 Alignment Principles

Prior to beginning any alignment procedure, a basic understanding of what you are trying to accomplish will make the procedure easier to perform. The following information is intended as a concise summary of the various factors that affect the optical alignment of the Laser Transducer System. As you are performing the alignment procedure keep the following points in mind:

a. The laser beam is the measurement standard. In order to achieve maximum accuracy, the beam must remain parallel to the path of travel.

b. The angular direction of the beam can be aligned by moving the laser head or adjusting a beam bender. The reflected beam can be aligned by adjusting a beam splitter or interferometer.

c. The angular direction of the beam will not be changed by adjusting a retroreflector nor will the transmitted beam direction be changed by adjusting a beam splitter or interferometer.

NOTE

> There is a 20-arcminute displacement of the beam when passing through the interferometer (see *Figure 11*).

d. To rough align the optics, you should start by aligning the laser head and the first moveable optical component. After this alignment is done move out one component at a time until the last component in that leg is aligned and the laser beam impinges on the receiver aperture.

e. The cube corners do not change the angular direction of the beam. However, they do displace the beam and reverse the direction. The laser beam remains parallel to its original path. In the case of the 10705A Single Beam Interferometer reference cube-corner and the 10704A Retroreflector the displacement is zero (i.e., the beam is reflected back on it's original path).

f. The interferometers are not sensitive to where on the aperture the laser beam comes in or goes out nor are they sensitive to the direction from which the beam is originated or reflected.

10.2 Alignment Tips

Understanding the following relationships between the movement of the retroreflector and the stationary interferometer will make it easier to decide how to align these two components in respect to each other. If the 10702A Linear Interferometer is the moving component, see *Figure 11* for an explanation of the Option 001 windows. If the 10705A Single Beam Interferometer is used it must be the stationary component. *Figure 52* shows a sequential relationship with the misalignment exaggerated for clarity. To initially align the components use the following sequence:

a. With the retroreflector as close as possible to the interferometer (position A of *Figure 52*), adjust any component (laser head, interferometer, or retroreflector) to get the small spots to overlap at the receiver (a receiver alignment target makes this adjustment easier).

b. Move retroreflector to position B and adjust the laser beam by angularly moving the laser beam until the small spots again overlap at the receiver.

NOTE

> As indicated by steps a and b, adjust the retroreflector to reduce alignment error when the distance between the components is small and adjust the laser beam when the distance is large.

c. Move the retroreflector back (position A″). If it does not align properly, move the retroreflector until the spots again overlap.

d. Move the retroreflector to position B′ and verify the system remains aligned. If necessary, repeat this procedure until you are certain that the optical leg being aligned remains aligned over the full path of travel.

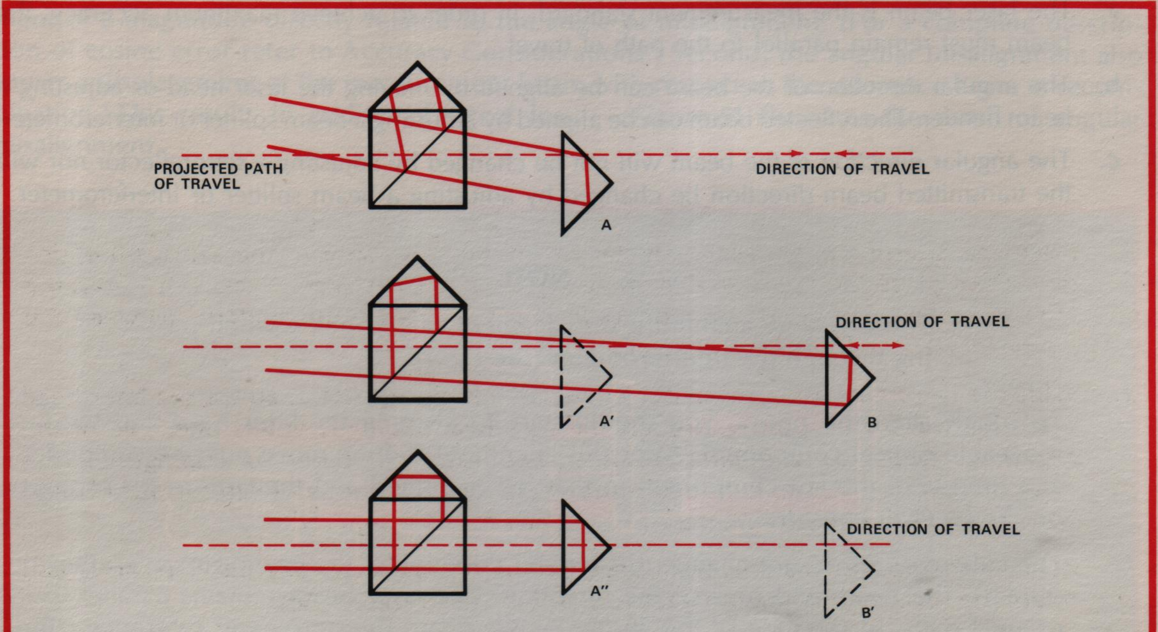


Figure 52. Alignment Tips

10.3 Visual Alignment Procedure

The visual alignment technique relies on the principle that if the measurement beam to the retroreflector is not parallel to the direction of travel, it is offset upon recombination with the reference beam of the interferometer (see *Figure 51*). When the interferometer and retroreflector are at the closest point to each other, the laser beam and optics are adjusted such that the reference and measurement beams completely overlap. When either the retroreflector or interferometer are moved along the measurement path, any angular misalignment causes a displacement of one laser beam with respect to the other which can be visually observed. Since the human eye can resolve a displacement of the beam of approximately 300 micrometres (0.01 inch) this technique can be applied for measurement travel of 0.5 metres (20 inches) or longer. For travel less than this, the sensitivity of this technique is normally not sufficient and autoreflection alignment should be used. The cosine error (E) in parts per million can be calculated from the following formula:

$$E = \frac{S^2}{8D^2}$$

Where D is the distance traveled in millimetres (inches) and S is the lateral offset of the returning beam in micrometres (thousandths of an inch). For example, if the distance traveled is 25 inches and this results in an offset of the return beam of 0.050 inches then:

$$E = \frac{(50)^2}{(8) \times (25)^2} = 0.5 \text{ parts per million or } 0.5 \text{ microinches error per inch of travel}$$

The techniques describing the two-axis visual alignment procedure can be followed for almost any measurement configuration. *Figure 53* is a typical measurement configuration which includes a linear interferometer and a single beam interferometer. In general, when the optical components are installed on the machine, their optical centerlines will be nominally in the correct relationship and only minor adjustments should be required.

When starting the adjustment procedure, one-axis at a time is adjusted. The first axis to be adjusted is the axis where any angular adjustment of the laser beam requires adjustment of the 5501A Laser Transducer (see X-axis, *Figure 53*). After angular adjustment, the laser head is locked down and any angular adjustment of the laser beam in the other measurement axes is accomplished by rotating the optical components. For visual alignment of the measurement system in *Figure 53*, perform the following procedure:

NOTE

Steps 1 through 10 constitute the X-axis visual alignment procedure.

1. Place the interferometer alignment target on the laser side of the X-axis interferometer and place the receiver alignment target on the receiver so that it is not in the laser beam (see *Figure 53c*, position 1). Place a piece of opaque material between the interferometer and the retroreflector.
2. With the retroreflector and interferometer at this closest point, adjust the laser head until the laser beam passes through the 50% Beam Splitter, enters one hole of the alignment target on the interferometer and exits the other to impinge on the receiver alignment target centered on the hole over the photodetector. A slight lateral adjustment of the interferometer or laser head may be required.
3. Remove the opaque material from between the retroreflector and interferometer and rotate the receiver alignment target to position 2 (see *Figure 53c*).
4. Adjust the retroreflector to center the return measurement beam on the receiver alignment target.

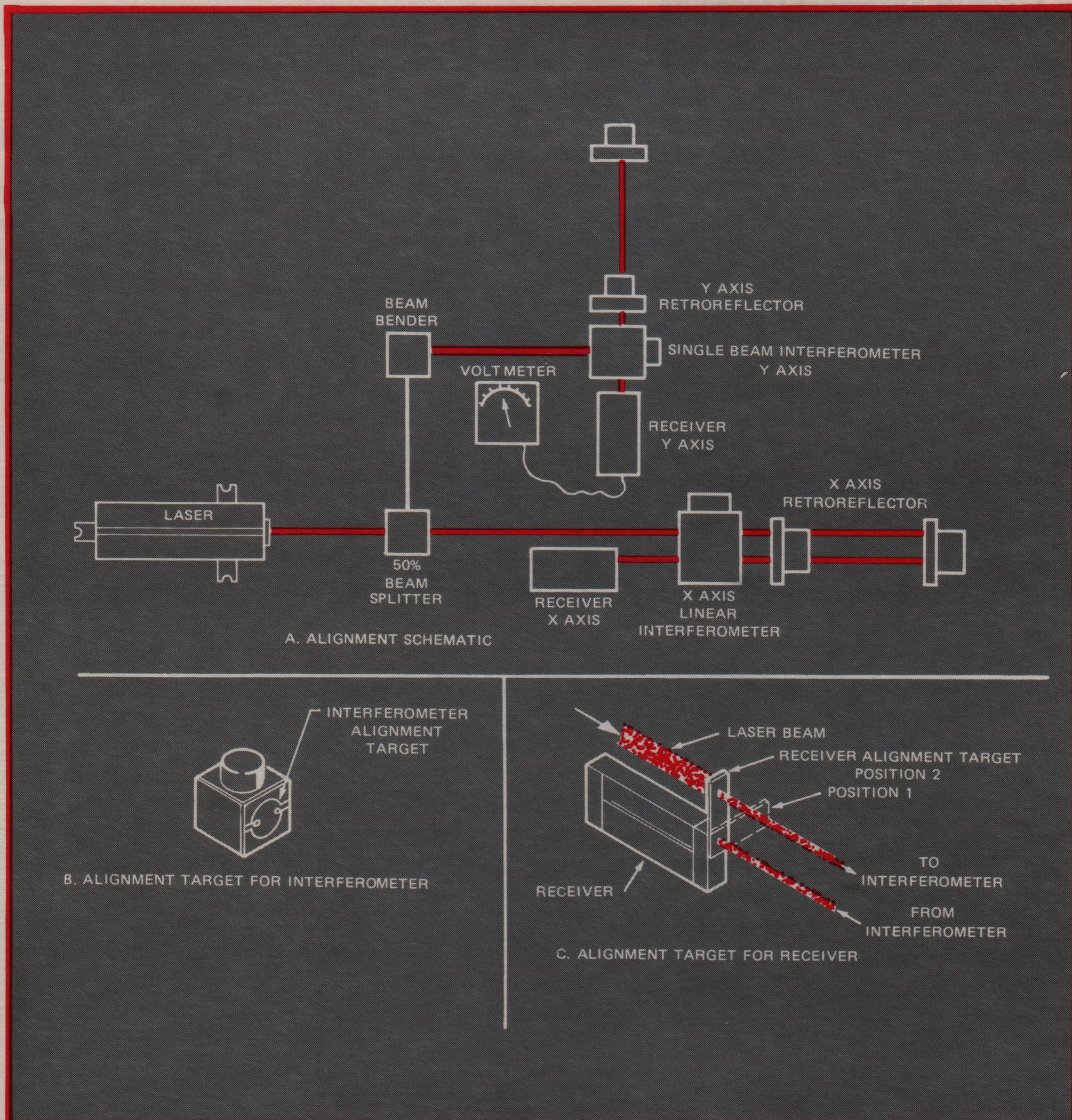


Figure 53. Visual Alignment

5. Traverse the retroreflector to its furthest point (at least 0.5 metres (20 inches)).
6. Adjust the laser head angularly to center the return beam on the receiver alignment target.
7. Return the retroreflector to the closest point to the interferometer.
8. Repeat steps 4 through 7 until the return beam is centered on the receiver alignment target at both ends of travel. An offset of 500 micrometres over a 0.5 metre travel is equal to a cosine error of 0.5 parts per million or 0.5 microns per metre of travel (0.5 microinches per inch).
9. If the reference beam returning from the interferometer is not centered on the receiver alignment target, adjust the interferometer until both the reference and measurement beams are centered.

NOTE

In Step 10, make sure the alignment is not disturbed.

10. Lock the laser head and X-axis optics down securely. Remove the receiver alignment target. Verify that the LED indicator on the receiver is illuminated and the voltage at the receiver test point is between 0.6 and 1.5 Vdc.

NOTE

Steps 11 through 20 constitute the Y-axis visual alignment procedure.

11. Place the alignment target on the Y-axis single beam interferometer and on the Y-axis receiver. Place a piece of opaque material between the single beam interferometer and the retroreflector.
12. Adjust the 50% beam splitter angularly until the reflected laser beam is centered in the beam bender entrance aperture. Slight lateral adjustments of the 50% beam splitter may be necessary to ensure there is no beam clipping. Lock down the 50% beam splitter securely.
13. Adjust the beam bender until the reflected beam is centered on the alignment target installed on the single beam interferometer. Lock the beam bender securely in place.
14. With the single beam interferometer and retroreflector at the closest point, adjust the single beam interferometer until the reference beam is centered on the receiver alignment target. Remove the opaque material.
15. Adjust the Y-axis retroreflector until the measurement beam is centered on the receiver alignment target.
16. Traverse the retroreflector to its furthest point of travel.
17. Angularly adjust the single beam interferometer to center the return beam from the retroreflector on the receiver alignment target. When adjusting the single beam interferometer angularly, it may also be necessary to make slight lateral adjustments to ensure that the reference beam from the single beam interferometer is also centered on the receiver alignment target.
18. Return the retroreflector to the closest point to the single beam interferometer.
19. Repeat steps 15 through 18 until the return beam from the retroreflector is centered on the receiver alignment target. Lock down the single beam interferometer securely making sure the alignment is not disturbed.
20. Remove the single beam alignment target and the receiver alignment target. Verify that the LED indicator on the receiver is illuminated and the voltage at the receiver test point is between 0.6 and 1.5 Vdc.

10.4 Autoreflection Alignment Procedure

The autoreflection alignment technique is used in short travel applications of less than 0.5 metre (20 inches). It is based on the principle of aligning a mirrored surface normal to the direction of travel and aligning the laser beam perpendicular to this mirrored surface (i.e., parallel to the direction of travel) to minimize cosine error. This technique is also used when it is necessary to make cosine error as small as possible regardless of travel distance.

Figure 54 shows a measurement setup similar to *Figure 53* except that the autoreflection technique is used for alignment.

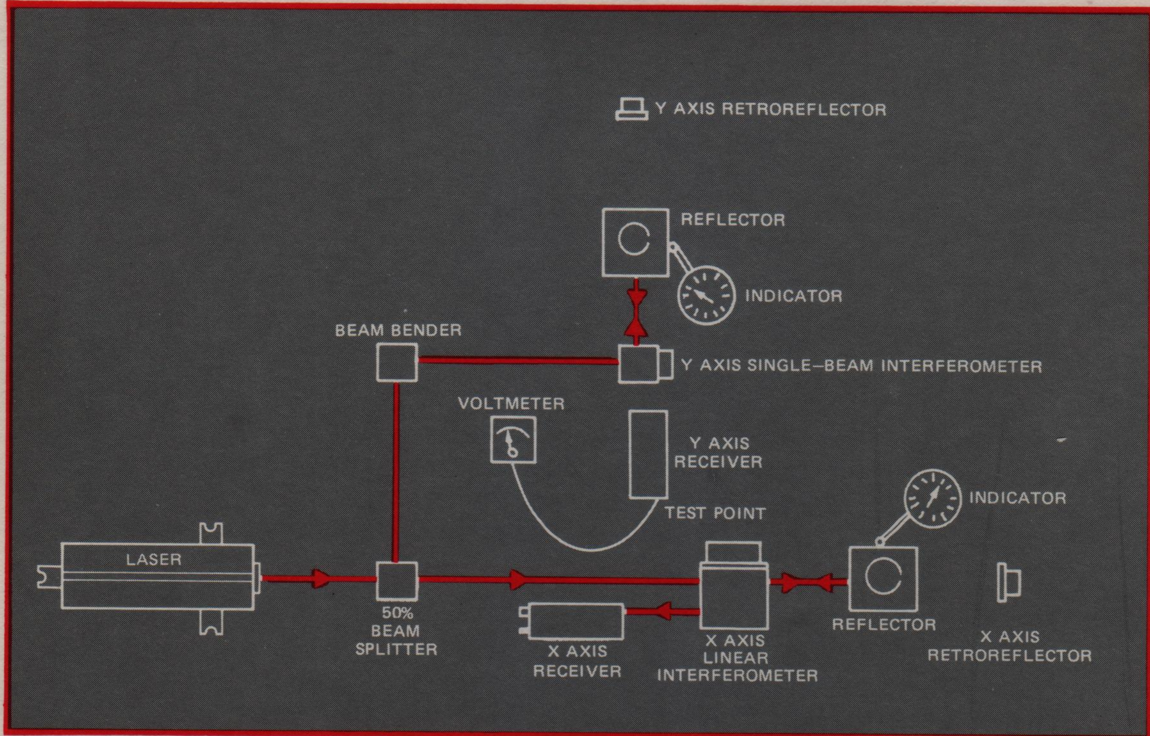


Figure 54. Autroreflection Alignment

For autoreflection alignment of the measurement system in *Figure 54,* perform the following procedure:

NOTE

Steps 1 through 11 constitute the X-axis autoreflection alignment procedure.

1. With all optical components in place, install the alignment targets on the interferometer and the receiver (*Figure 53c,* position 1). Place a piece of opaque material in front of the retroreflector.

2. With the laser beam passing through the 50% beam splitter, adjust the laser head and interferometer until the laser beam enters one hole of the alignment target and exits the other to impinge on the receiver alignment target centered on the hole over the photodetector.

3. Place a reflector* between the interferometer and retroreflector so that the measurement beam from the interferometer strikes its reflective surface. The reflector's sides must be perpendicular to its front face within stringent tolerances (<15 arcseconds).* Align the reflector with a precision indicator until its front surface is perpendicular to the direction of travel in both angular axes.

4. Turn the front turret of the laser head to select the small aperture.

**A typical reflector is the TRUE SQUARE manufactured by the Starret Co. This reflector, as well as other similar commercially available reflectors, have proved ideal for this application. Gage blocks (Jo-blocks) should not be used since their sides may or may not be perpendicular to their faces, depending on the technique of their manufacture.*

NOTE

If the distance between the laser head and the reflector is 0.5 metres (20 inches) or more, the formula given in the paragraph on Visual Alignment determines the cosine error based on the offset of the return beam at the laser head. For example, a distance between the laser head and reflector of 0.5 metres (20 inches) and an offset of the return beam at the small aperture of the laser of 500 micrometres (0.0202 inches) the cosine error is approximately 0.5 parts per million.

5. Adjust the laser head angularly until the return beam reflected from the reflector returns and is centered on the small aperture of the laser head. Slight lateral adjustments of the interferometer may be required to ensure that the reference beam from the interferometer is centered on the receiver alignment target.

NOTE

For high accuracy alignment and installations where there is less than 0.5 metre (20 inches) between the laser head and reflector, perform steps 6 through 8.

6. Remove the receiver alignment target and interferometer alignment target and rotate the turret of the laser head to select the large aperture.
7. With a fast responding voltmeter (preferably a meter type) attached to the receiver test point, angularly fine adjust the laser beam (laser head or interferometer, depending on axis) until a signal is received on the receiver. (The voltmeter will suddenly jump to some value greater than 0.25 volts.) This is a critical adjustment and may initially require great care to achieve the desired result.
8. Peak the voltmeter reading (which will be fluctuating) by fine adjusting the laser beam in both angular axes. This will align the laser beam to within ±15 arcseconds to the reflector surface. If the reflector surface is aligned to the direction of travel within ±15 arcseconds, the laser beam will be aligned to the direction of travel within ±30 arcseconds or approximately 0.04 parts per million. That is 0.04 micrometre per metre of travel (0.04 microinches per inch) of cosine error.
9. Lock down the laser head and interferometer securely. Make sure the alignment is not disturbed. Remove the reflector and the opaque material.
10. Adjust the retroreflector until the return measurement beam is centered on the receiver alignment target and overlaps the reference beam from the interferometer.
11. Remove the receiver alignment target and interferometer alignment target and rotate the turret on the laser head to the large aperture. Verify that the LED indicator on the receiver is illuminated and the voltage at the receiver test point is between 0.6 and 1.5 Vdc.

NOTE

Steps 12 through 21 constitute the Y-axis autoreflection alignment.

12. Adjust the 50% beam splitter angularly until the reflected laser beam is centered on the beam bender aperture. Slight lateral adjustments of the 50% beam splitter may be necessary to ensure there is no beam clipping. Lock down the 50% beam splitter securely.
13. Adjust the beam bender until the reflected beam is centered on the aperture of the single beam interferometer. The single beam interferometer alignment target can be used as an aid and then removed. Lock down the beam bender securely.
14. Place the receiver alignment target on the receiver and rotate the turret of the laser head to select the small aperture.

15. Place a reflector between the interferometer and the retroreflector so that the measurement beam from the interferometer strikes its reflective surface. Align the reflector with a precision indicator until its front surface is perpendicular to the direction of travel in both angular axes (<15 arcseconds).

16. Place a single beam interferometer alignment aid on the output-side of the interferometer and adjust the single beam interferometer angularly until the return beam reflected from the reflector returns and is centered on the small aperture of the laser head. Slight lateral adjustments of the interferometer may be required to ensure that the reference beam from the interferometer is still centered on the receiver alignment target. Do not adjust the laser head.

NOTE

For high accuracy alignment and installations where there is less than 0.5 metre (20 inches) between the laser head and reflector, perform steps 17 through 19.

17. Remove the receiver alignment target and interferometer alignment target and rotate the turret of the laser head to select the large aperture.

18. With a fast responding voltmeter (preferably a meter type) attached to the receiver test point, angularly fine adjust the laser beam (laser head or interferometer, depending on axis) until a signal is received on the receiver. (The voltmeter will suddenly jump to some value greater than 0.25 volts.) This is a critical adjustment and may initially require great care to achieve the desired result.

19. Peak the voltmeter reading (which will be fluctuating) by fine adjusting the laser beam in both angular axes. This will align the laser beam to within ±15 arcseconds to the reflector surface. If the reflector surface is aligned to the direction of travel within ±15 arcseconds, the laser beam will be aligned to the direction of travel within ±30 arcseconds or approximately 0.04 parts per million. That is, 0.04 micrometre per metre of travel (0.04 microinches per inch) of cosine error.

20. Lock down the single beam interferometer securely making sure the alignment is not disturbed. Remove the reflector.

21. Remove the receiver alignment target and interferometer alignment target and rotate the turret on the laser head to the large aperture. Verify that the LED indicator on the receiver is illuminated and the voltage at the receiver test point is between 0.6 and 1.5 Vdc.

10.5 Plane Mirror Interferometer Alignment Procedure

This procedure covers specifically the alignment of the 10706A Plane Mirror Interferometer as applied to an X-Y positioning device using flat mirrors as retroreflectors. In this procedure it is assumed that the mirror surfaces are flat to within the tolerances required for operation of the plane mirror interferometer (refer to Measurement Components) and they have been aligned perpendicular to each other and perpendicular to their respective directions of travel. *Figure 55* illustrates the most common 2-axis plane mirror interferometer installation.

The alignment of the plane mirror interferometer is very similar to the autoreflection alignment technique previously described. In most cases, the accuracy demands of the X-Y positioning devices used, along with the relatively short travels encountered, dictate that the high accuracy alignment technique described in the autoreflection alignment procedure be used.

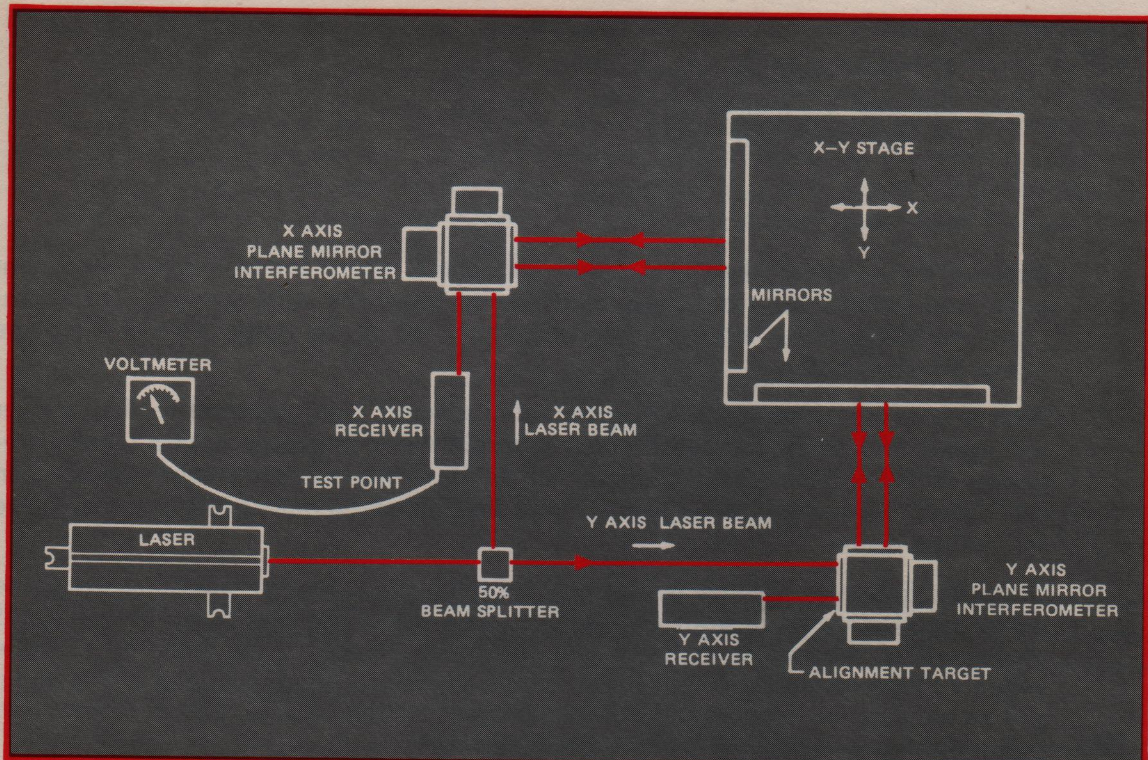


Figure 55. Plane Mirror Interferometer Alignment

NOTE

Steps 1 through 10 constitute the Y-axis alignment.

1. Place the interferometer alignment target on the laser side of the Y-axis plane mirror interferometer and the receiver alignment target on the receiver (*Figure 53c*, position 1). Place a piece of opaque material between the Y-axis plane mirror interferometer and the mirror.
2. Adjust the laser head until the laser beam passes through the 50% beam splitter, enters one hole of the interferometer alignment target and exits the other centered on the receiver alignment target. Lock down the laser head securely.
3. Select the small aperture of the front turret of the laser head and install the alignment aid on the output of the plane mirror interferometer in the correct orientation. Remove the opaque material from between the plane mirror interferometer and the mirror.
4. The laser beam will now exit the interferometer and be reflected by the mirror upon itself back into the interferometer. Angularly adjust the plane mirror interferometer until the beams reflected from the mirror returns through the plane mirror interferometer and back to the small aperture of the laser head. Slight lateral adjustments of the plane mirror interferometer may be required to ensure that the reference beam is still centered on the receiver alignment target. If the distance between the mirror and the laser head is at least 0.5 metres (20 inches) then the formula given in the section on Visual Alignment determines the cosine error based on the offset of the return beam at the laser head.

NOTE

For high accuracy alignment and installations where there is less than 0.5 metres (20 inches) between the laser and mirror, perform steps 5 through 7.

5. Remove the receiver alignment target and plane mirror interferometer alignment target and rotate the turret of the laser head to select the large aperture. Do not remove the plane mirror interferometer alignment aid on the output side of the plane mirror interferometer.

6. With a fast responding voltmeter (preferably a meter type) attached to the receiver test point, fine adjust the plane mirror interferometer angularly until a signal is received on the receiver. (The voltmeter will suddenly jump to some value greater than 0.25 volts.) This is a critical adjustment and may initially require great care to achieve the desired result.

7. Peak the voltmeter reading (which will be fluctuating) by fine adjusting the plane mirror interferometer in both angular axes. This aligns the laser beam to within ±15 arcseconds to the mirror. If the mirror has been aligned to the direction of travel within ±15 arcseconds, the laser beam will be aligned to the direction of travel within ±30 arcseconds, or approximately 0.04 parts per million. That is, 0.04 micrometre of travel (0.04 microinches per inch) of cosine error.

8. Lock down the plane mirror interferometer securely, making sure the alignment is not disturbed.

9. Remove the plane mirror interferometer alignment target and alignment aid. The reference beam and the measurement beam must be centered on the receiver alignment target.

10. Remove the receiver alignment aids and rotate the turret on the laser head to the large aperture. Verify that the LED indicator on the receiver is illuminated and the voltage at the receiver test point is between 0.6 and 1.5 Vdc.

NOTE

Steps 11 through 20 constitute the X-axis alignment.

11. With the laser head turret in the large aperture position, place the plane mirror interferometer alignment target on the laser head side of the X-axis plane mirror interferometer and the receiver alignment target on the receiver (*Figure 53c*, position 1). Place a piece of opaque material between the X-axis plane mirror interferometer and the mirror.

12. Angularly adjust the 50% beam splitter until the laser beam enters one hole of the plane mirror interferometer alignment target and exits the other centered on the receiver alignment target (do not adjust the laser head). Slight lateral adjustments of the 50% beam splitter may be necessary to ensure there is no beam clipping. Lock down the 50% beam splitter securely.

13. Select the small aperture on the front turret of the laser head and install the alignment aid on the output of the plane mirror interferometer in the correct orientation. Remove the opaque material from between the plane mirror interferometer and the mirror.

14. The laser beam now exits the interferometer and is reflected by the mirror back upon itself into the interferometer. Angularly adjust the plane mirror interferometer until the beam reflected from the mirror returns through the plane mirror interferometer and back to the small aperture of the laser head. Slight, lateral adjustments of the plane mirror interferometer may be required to ensure that the reference beam is still centered on the receiver alignment target. If the distance between the mirror and the laser head is at least 0.5 metres (20 inches) then the formula given in the section on Visual Alignment will determine the cosine error based on the offset of the return beam at the laser.

NOTE

For high accuracy alignment and installation where there is less than 0.5 metres (20 inches) between the laser and mirror, perform steps 15 through 17.

15. Remove the receiver alignment target and plane mirror interferometer alignment target and rotate the turret of the laser head to select the large aperture. Do not remove the plane mirror interferometer alignment aid on the output side of the plane mirror interferometer.

16. With a fast responding voltmeter (preferably a meter type) attached to the receiver test point, fine adjust the plane mirror interferometer angularly until a signal is received on the receiver. (The voltmeter will suddenly jump to some value greater than 0.25 volts.) This is a critical adjustment and may initially require great care to achieve the desired result.

17. Peak the voltmeter reading (which will be fluctuating) by fine adjusting the plane mirror interferometer in both angular axes. This aligns the laser beam to within ±15 arcseconds to the mirror. If the mirror has been aligned to the direction of travel within ±15 arcseconds, the laser beam will be aligned to the direction of travel within ±30 arcseconds, or approximately 0.04 parts per million. That is, 0.04 micrometre of travel (0.04 microinches per inch) of cosine error.

18. Lock down the plane mirror interferometer securely. Make sure the alignment is not disturbed.

19. Remove the plane mirror interferometer alignment target and alignment aid. The reference beam and the measurement beam must be centered on the receiver alignment target.

20. Remove the receiver alignment aids and rotate the turret on the laser head to the large aperture. Verify the LED indicator on the receiver is illuminated and the voltage at the receiver test point is between 0.6 and 1.5 Vdc.

11 CONCLUSION

The HP 5501A Laser Transducer System provides an accuracy of ± one-half part per million within a range of 200 feet. Its optics are no more complex to apply compared to conventional transducers such as the Inductosyn Scale or Rack and Pinion. The Laser Transducer System is ruggedly built, requires similar protection compared to other less precise position transducers, even under the harsh machine shop environment. While the HP 5501A optics are less time consuming to set up, the total system will keep its superior accuracy once the optics are aligned. If, for some reason the alignment is lost and measurement is no longer possible, the user will be alerted by the system. This is not true of conventional position transducers which may shift out of alignment with time and introduce a positioning error which is unknown to the system until either a calibration of positioning accuracy has been performed or improperly machined parts appear.

Overall, while the 5501A Laser Transducer System may appear to be difficult to use initially, once the concepts and requirements as described in this application note are understood the user will see that applying laser positioning capability to the system is no more difficult than applying any of the various conventional position transducers, while the advantages of high accuracy, increased reliability, and less maintenance will be required.