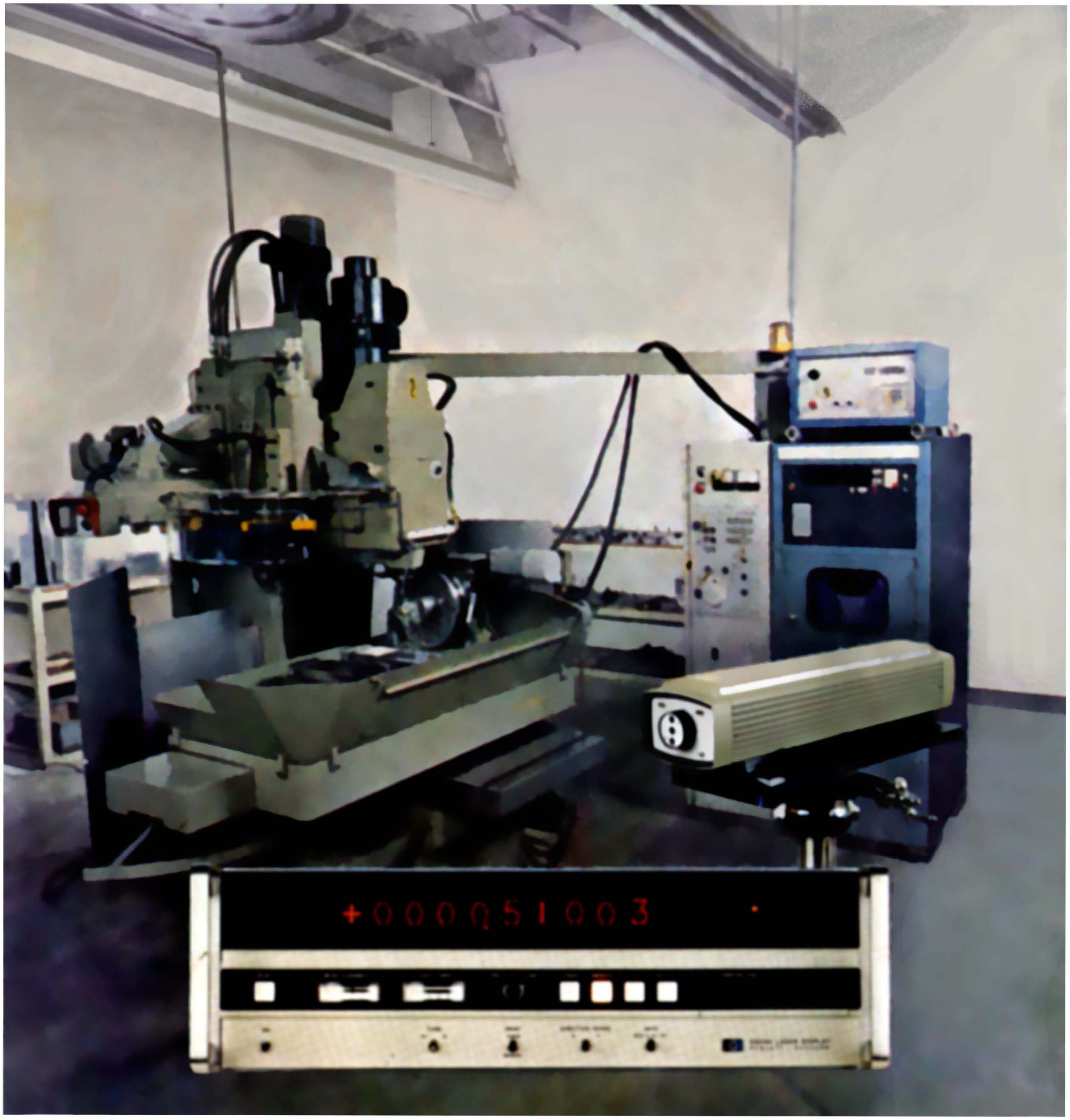
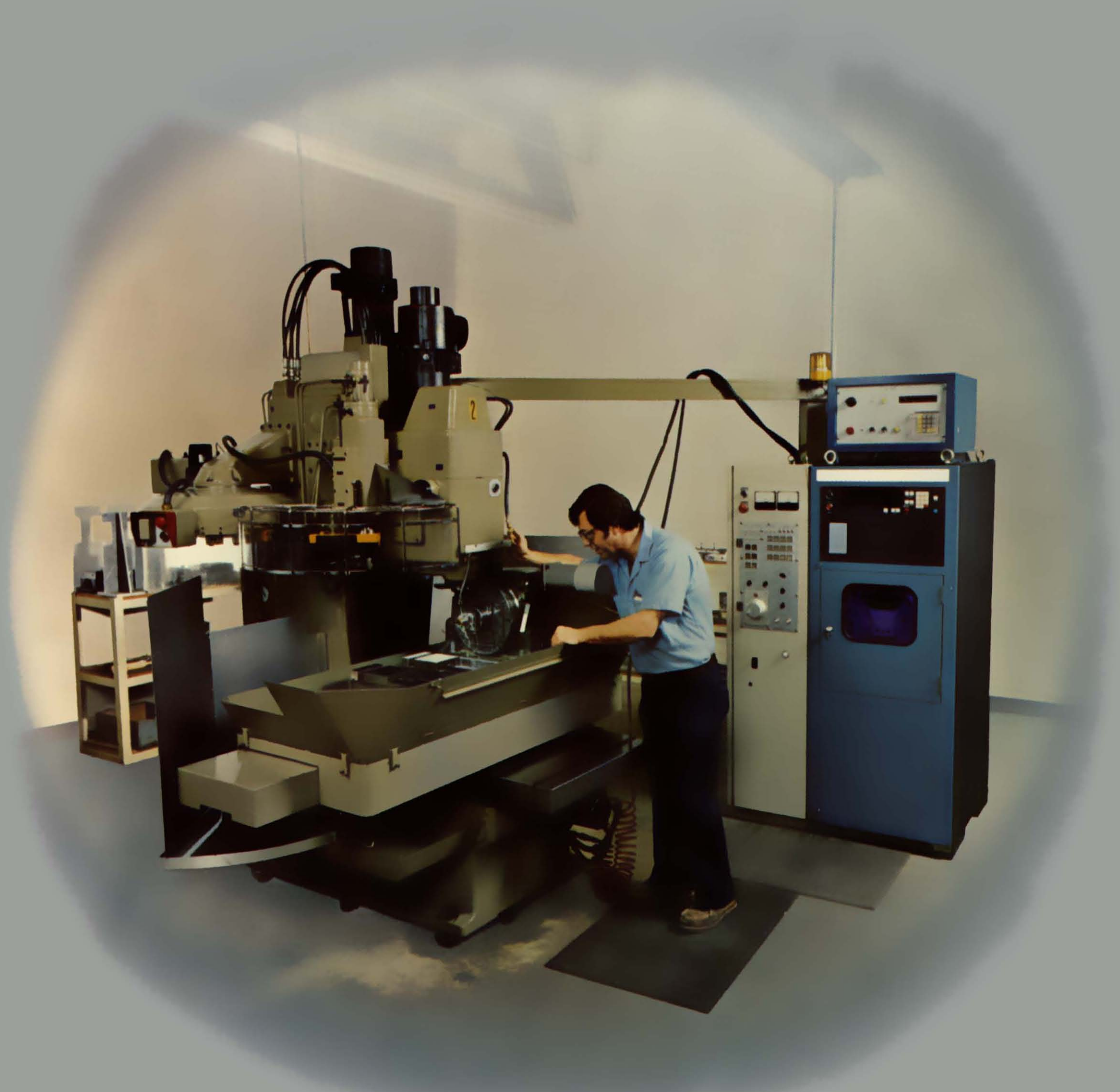
HEWLETT PACKARD

Laser Measurement System

5526A



Increase Your Productivity & Quality While Reducing Scrap & Machine Down Time . . .



What causes your machine tool maintenance problems?

- Linear positioning errors?
- Axes not square to one another?
- Travel not straight?
- Pitch and yaw errors in table/head travel?

Laser Measurement System

The 5526A is a laser interferometer which is fundamentally a linear displacement measuring device. It uses the wavelength of light from a unique Helium-Neon laser as a length standard to make linear measurements with 0.01 μm (1 microinch) resolution and ±0.5 parts per million accuracy over a measurement range of up to 61 m (200 ft).

The basic system consists of a laser head, a remote interferometer, a reflector and a digital display.

With the addition of other accessories the Laser Measurement System (LMS) may be configured to measure angle, flatness, straightness, perpendicularity and to automatically record deviations as a function of linear position in graphical form.

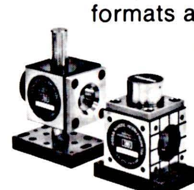
HP's patented, two-frequency laser permits accurate measurements to be made reliably over large distances - even in hostile atmospheres such as air turbulence, oil mist or thermal gradients. The unique electro-optical design of the LMS makes it easy to align with the measurement axis which, in turn, reduces set-up time.

The 5500C Laser Head has two measurement channels. Therefore, by adding another interferometer and display, two measurements can be done simultaneously. This feature opens up more applications, such as closed-loop control of an XY positioning system.

The measurement is displayed on a digital readout with 9 digits and ± sign. Four operating modes are provided in the Display: NORMAL, SMOOTH, X10 and VELOCITY. The NORMAL mode provides high resolution and high update rate, useful where it is required to follow rapid motion or to provide feedback for closed-loop systems. The SMOOTH mode has the same resolution, but averages many readings to give jitter free display in a vibrating environment. The X10 mode provides one more digit of resolution and is also smoothed. The VELOCITY mode displays the velocity of the displacement being measured.

A unique feature of the 5505A Display is that the operator is free to select units or modes of operation at will during a measurement without loss of data.

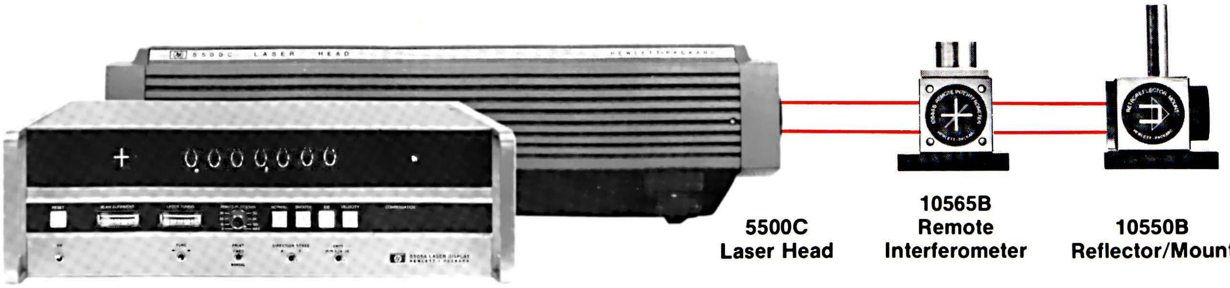
Measurement data is available at the Laser Display rear panel in BCD format. This makes for easy interfacing to a wide variety of recording, controlling and computing devices, many of which are available from Hewlett-Packard. Optional rear panel output formats available include an analog signal for linear position error plotting.



Optics used to measure linear displacement.

5505A Laser Display, displays distance and straightness measurements in mm, inch and λ/4 units. Angular measurements displayed in arc-seconds. Velocity measurements displayed in mm/sec, mm/min, inch/sec, inch/min.

5500C Laser Head, a unique two-frequency Helium-Neon Laser.



The passive and versatile 10565B Remote Interferometer and the 10550B Retroreflector are used to make linear displacement measurements of up to 61 m (200 ft) with an accuracy of ±0.5 parts per million.

A major application of the linear interferometer system is in the calibration of the positioning accuracy of numerically controlled machine tools and coordinate measuring machines (see Figure 1). Velocity measurement for the calibration of machine tool feedrate is accomplished with the same optical setup. In the metrology laboratory, the interferometer system is useful for the calibration of other length standards such as micrometer heads, glass and metal scales.

Distance change between the interferometer and the retroreflector is measured; not the absolute distance between them. Thus any point may be defined as a zero reference.

An advantage of the laser interferometer is that since the optics are passive no heat is generated to distort the device under test and thus invalidate the measurement. The Laser Head can be mounted on a 10580A Laser Tripod some distance away leaving only passive, non-heat producing optics in contact with the device being measured.

Setup time is reduced with the use of the Tripod. One setup of the laser head allows linear, angular and straightness measurements by just changing the optical components. The optics are designed to be easily mounted with standard machine tool clamping hardware.

Additional accessories convert the 10565B Remote Interferometer into an interferometer for measuring angles or displacement of plane mirrors as shown in later sections. This versatility results in savings to the user by minimizing the number of optical components required.

Required Equipment

5500C	**Laser Head**
5505A	**Laser Display**
10565B	**Remote Interferometer**
10550B	**Reflector/Mount**

Recommended Equipment

10580A	**Laser Tripod**
5510A	**Automatic Compensator**
10563A	**Material Temperature Sensor**

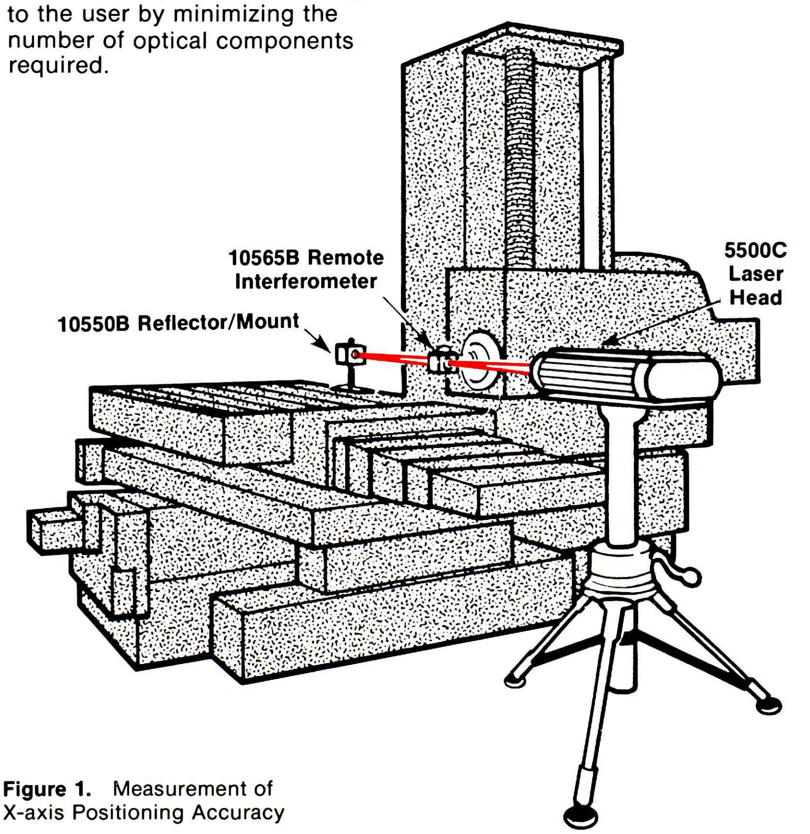
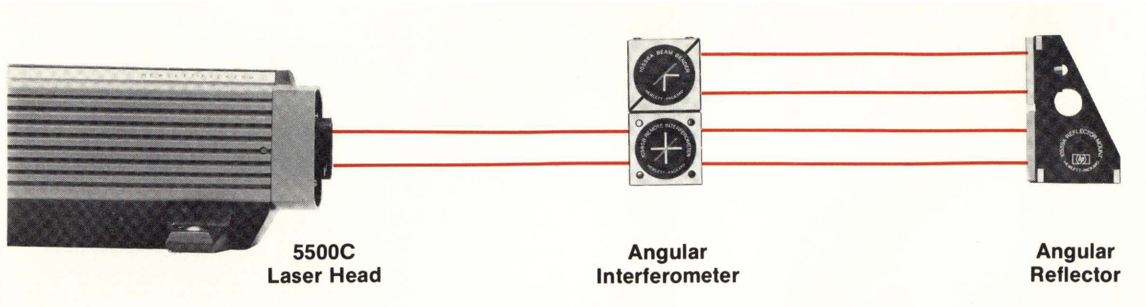


Figure 1. Measurement of X-axis Positioning Accuracy

Angular/Flatness Measurement



Unwanted angular motions in a machine tool can cause errors in the cutting of parts, thus increasing the production cost. It is therefore important, when evaluating a machine tool or a measuring machine, to determine the error contributions of its pitch and yaw motions along each axis of travel.

Pitch and Yaw By simply adding the 10558A Beam Bender to the 10565B Remote Interferometer (a component of the Linear measurement optics), the Angular Interferometer is created. The Angular Reflector is made by inserting the two Retroreflectors (which are also a part of the Linear optics) into the 10559A Reflector Mount.

As shown in Figure 2 below, angular deviations between the machine table and column during travel are measured by the angular optics and displayed directly in arc-seconds on the 5505A Laser Display. Since the set-up for the angular motion is virtually the same as that for measurement of linear displacement shown in Figure 1, only one alignment of Laser Head is required.

Flatness The same optical components which were used to check pitch and yaw motions can also be used to make flatness measurement of machine tool beds and surface plates.

The HP Laser Measurement System offers many advantages over conventional instruments such as auto-collimators and levels. Most significantly, it reduces the time required to make the measurement and improves both the repeatabilty and the accuracy of the readings.

Since the Laser Head is mounted off the surface plate on a tripod, potentially serious distortions due to heat and mass are avoided.

For rapid surface plate calibration, the 10557A Turning Mirrors are specifically designed to deflect the measuring beams to the various measurement lines required to characterize the plate. Only a

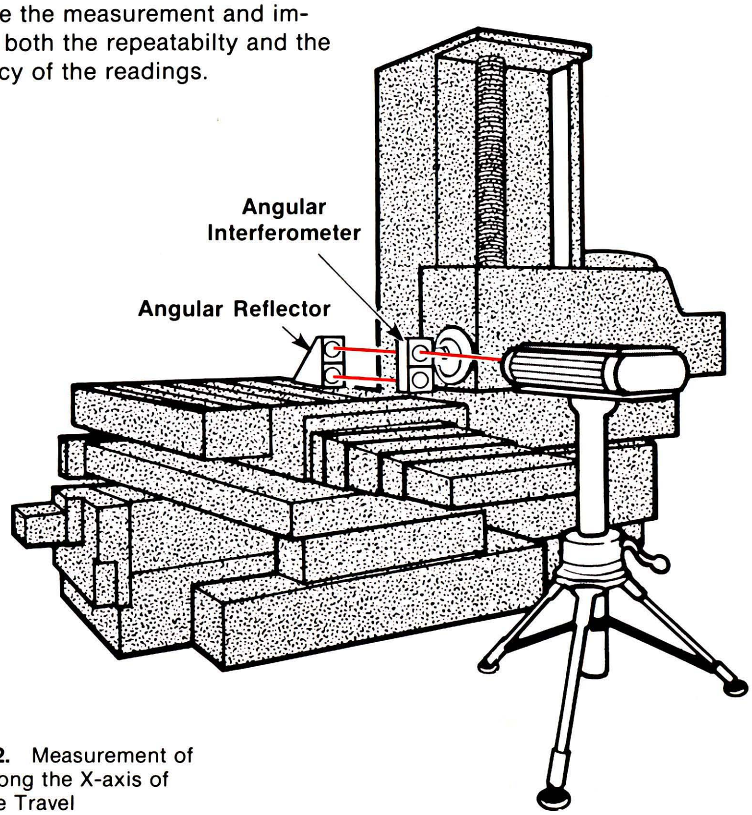


Figure 2. Measurement of pitch along the X-axis of Machine Travel

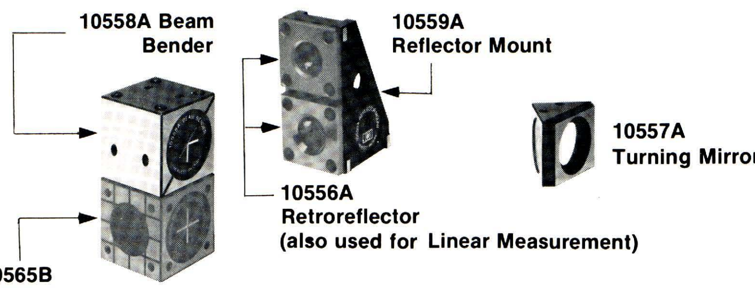


Figure 3. Optical Components used for Angular/Flatness Measurement

single set-up of the Laser Head is necessary. See Figure 4.

Deviations in surface flatness are read-out directly in millimetres or inches. This eliminates the conversion from arc-seconds required with conventional methods.

Data can be rapidly recorded on a printer during the calibration or, to increase overall timesavings even more significantly, it can be transferred directly into an HP Desktop Computer. The Desktop Computer automatically calculates and plots numeric data, and a graphical representation of the surface contour (see Figures 11 and 12).

Flatness measurements are made easier with the use of a 10583A Footspacing Kit. It consists of baseplates providing a two-inch, four-inch and six-inch pad spacing for the 10559A Reflector Mount to give the user the flexibility needed to minimize the grid set-up time and data accumulation time required.

The resolution for Flatness measurement is 0.01 micrometre (1 microinch) with an accuracy of ±0.5 parts per million.

Required Equipment

Linear Measurement Optics (see page 3)
10558A Beam Bender
10559A Reflector Mount
10557A Turning Mirror (2 each required for surface plate calibration only)
10583A Footspacing Kit (optional)

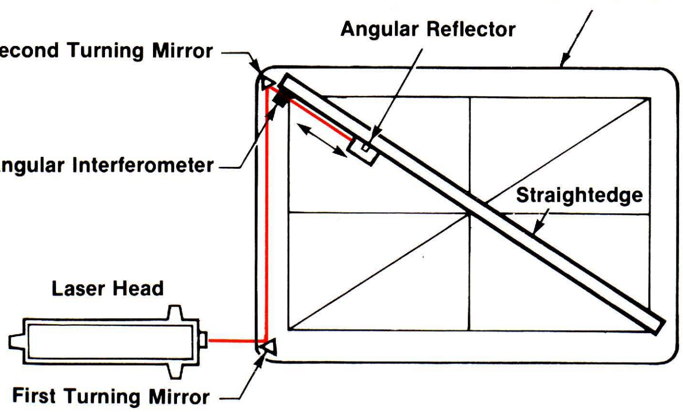
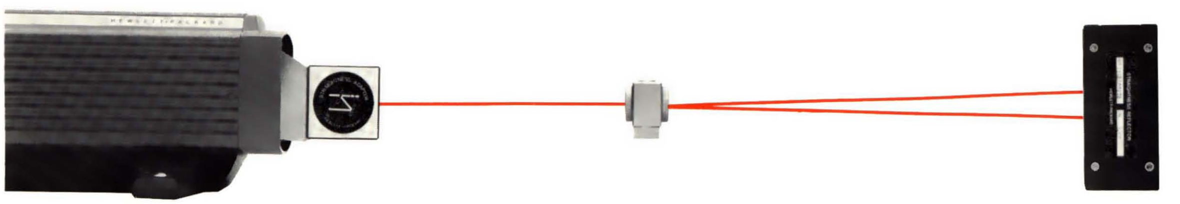


Figure 4. For surface plate calibration, only the optical components need be mounted on the surface plate. All required measurements can be made with the 550C Laser Head in one position.

Straightness/Squareness Measurement



Knowing positioning accuracy and pitch/yaw motions of all axes is very helpful in evaluating machine tool capability, but it is not the whole story. The HP Laser Measurement System has been designed to make complete calibration of machine geometry, including Straightness and Parallelism of travel plus Perpendicularity of axes.

Straightness The HP Straightness Interferometer is a highly accurate optical "straightedge" which is capable of measuring the straightness of travel of machine tool and measuring machine coordinate motions with interferometric accuracy. Out-of-straightness is read out directly in millimetres or inches by the same Laser Display that is used for linear and angular measurements.

The HP system is more accurate and less sensitive to air turbulence than alignment lasers or other optical devices. It is compact enough to be mounted on small machines yet straightness of travel can be measured over a range of 30 m (100 ft). See Figure 6.

The 10690A Short-Range Straightness Interferometer is used for straightness measurement of up to 3 m (10 ft) with a resolution of 0.01 μm (1 microinch). For straightness measurement of 1m out to 30 m (3 ft to 100 ft), the 10691A Long-Range Straightness Interferometer is used. The resolution of this version is 0.1 μm (10 microinches).

Computing and recording of the geometric characteristics of the machine being calibrated are facilitated by the use of a Desktop Computer and Plotter System which accepts data directly from the Laser Display. Specially developed metrology and machine tool calibration programs are available for use in straightness, parallelism and squareness measurements.

Parallelism The same equipment used for making straightness measurement can also be used for measuring parallelism. For instance, the degree of parallelism between a spindle axis and a coordinate motion can easily be measured by mounting the straightness reflector in the spindle and rotating it through 180 degrees between two successive straightness calibrations. Out-of-parallelism is then given by half the angle between the resultant two straightness measurements. Figure 5 illustrates a set-up for measuring the straightness of travel and out-of-parallelism of a lathe carriage axis to the spindle rotation axis.

Squareness The straightness accessories are also able to make squareness measurements with the addition of a 10692B Optical Square. The Optical Square bends the optical

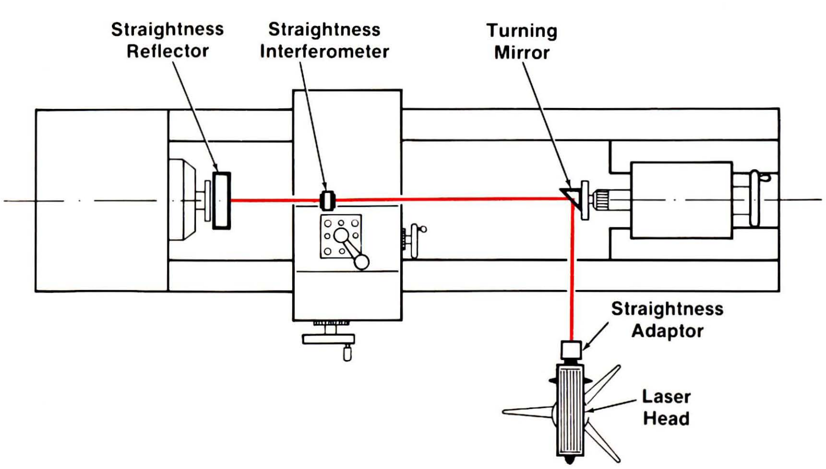
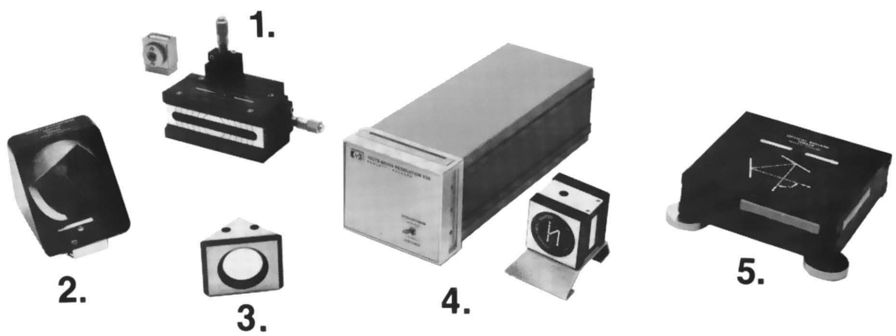


Figure 5. Straightness and Parallelism Set-up on Lathe



Accessories used for measuring straightness of travel and squareness of axes.

1. **Straightness Interferometer and Reflector**
2. **10693A Vertical Straightness Adaptor**
3. **10557A Turning Mirror**
4. **10579A Straightness Adaptor and Resolution Extender**
5. **10692B Optical Square**

straight-edge precisely 90 degrees. This enables the operator to make straightness and hence squareness measurements of two orthogonal axes.

For example: Y-axis out-of-straightness is measured first as shown in Figure 6. By adding a 90 degree bend to the Straightness Reflector with the 10692B Optical Square, and relocating the Laser Head to the position shown in Figure 7, out-of-straightness in the X-axis is measured. A comparison of the two straightness measurements with respect to the 90 degree reference established by the Optical Square yields out-of-squareness.

The Desktop Computer/Plotter accessory performs all calculations and creates a graph depicting out-of-straightness, out-of-squareness and/or out-of-parallelism. Sample plots are shown in Figure 10 on page 11.

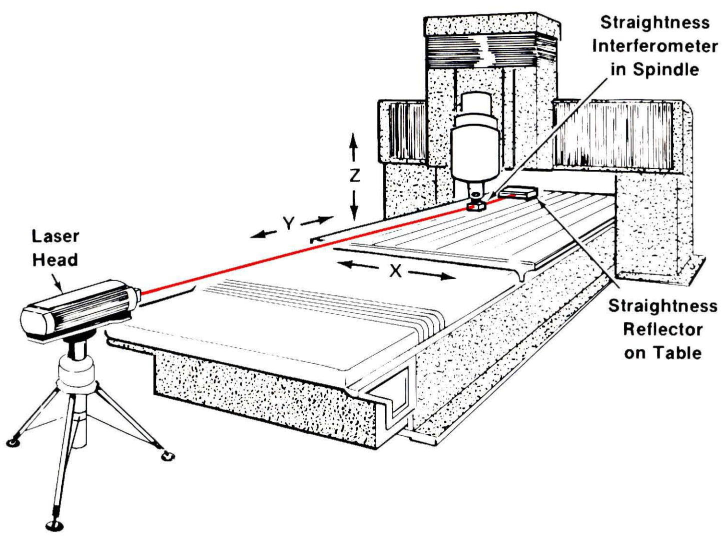


Figure 6. Set-up for Y-Axis Straightness Measurement

Required Equipment

5500C	**Laser Head**
5505A	**Laser Display**
10693A	**Vertical Straightness Adaptor**
10557A	**Turning Mirror**
10579A	**X36 Resolution Extender Straightness Adaptor**
10690A	**Short-Range Straightness Interferometer and Reflector From 0.1m-3m (4 in-10 ft)**
10691A	**Long-Range Straightness Interferometer and Reflector From 1m-30m (3 ft-100 ft)**
10692B	**Optical Square (required for Squareness)**

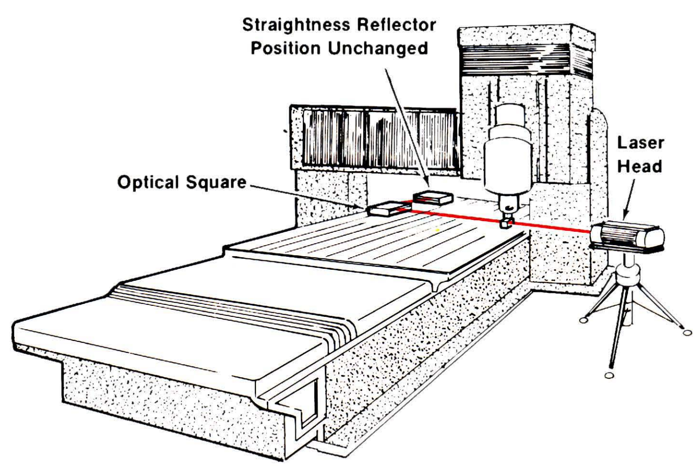


Figure 7. Set-up for the Measurement of X-Axis Straightness and Squareness of X-Axis to Y-Axis

Specifications

Measurement	Linear
Range	Up to 61 m (200 ft) depending on conditions.
Accuracy	**Metric:** ±0.5 parts per million ±2 counts in last digit. **Inch:** ±0.5 parts per million ±1 count in last digit.
Resolution	**Normal and Smooth Modes** **Metric:** 0.000 1 millimetre **Inch:** 0.000 01 inch **X10 Mode** **Metric:** 0.000 01 millimetre **Inch:** 0.000 001 inch With 10552A Resolution Extender an additional digit can be resolved in all modes of operation.
Weights	**10565B Remote Interferometer:** 1.1 kg (2.7 lbs) **10550B Reflector/Mount:** 0.8 kg (2.0 lbs)
Dimensions	See back page.

5526A Laser Measurement System

The following are general specifications which apply to all types of measurement made with the 5526A Laser Measurement System. Specifications which pertain to a specific measurement are contained above.

Laser: Helium-Neon type with Zeeman-split 2-frequency output. Fully automatic tuning.

Maximum Allowable Signal Loss: 95% (−13 dB)

Maximum Lateral Offset of Return Beams: ±5 mm (±0.2 inch) The remote interferometer or the cube-corner retroreflector may be offset by a maximum of ±2.5 mm (±0.1 inch) since the reflected beam is displaced by twice the cube-corner displacement.

Maximum Measuring Velocity: 0.3m/sec (720 inch/min)

Velocity Measurement Accuracy: ±4.0 micrometres/sec (±0.01 in/min)

Atmospheric and Material Temperature Compensa
Manual input from tables supplied. Automatic co
tion optional.

OPERATING

Display: 9 digits with appropriate decimal point, co
+ or − sign.

Units:

Distance Modes: millimetres, inches, λ/4

Velocity Mode: mm/second, mm/minute, inches
inches/minute

Display Overflows:

Normal and Smooth Modes: 79,000 mm (79m); 3,1
(258 feet); 500,000,000 λ/4

X10 Mode: 10,000 mm (10m); 620 inches (51 feet); 100,000,000 λ/4

Angular/Flatness	Straightness/Squareness
Up to ±10 degrees.	**Short Range:** 0.1 m - 3 m (4 in. - 10 ft.) ±5% **Long Range:** 1 m - 30 m (3 ft. - 100 ft.) ±10%
Angular ±0.1 arc-second ±1 count in last digit up to ±100 arc-seconds. ±1 arc-second ±1 count in last digit up to ±1000 arc-seconds. ±4 arc-seconds per degree ±1 count in last digit up to ±10 degrees. Correction required for angular displacements greater than 50 arc-minutes. **Flatness** Same as Linear Measurement	**Metric:** ±0.4 micrometre/metre ±2 counts in last digit **Inch:** ±5 microinches/foot ±1 count in last digit
Angular Normal Mode, Inch units selected: 1 arc-second. X10 Mode, Inch units selected: 0.1 arc-seconds. With 10552A Resolution Extender an additional digit can be resolved in all modes of operation. **Flatness** Same as Linear Measurement.	**Short Range:** Same as Linear Measurement **Long Range:** One-tenth that of short range version
10558A Beam Bender: 680 g (1.5 lbs) **10559A Reflector Mount:** 990 g (2.2 lbs) **10557A Turning Mirror:** 450 g (1.0 lb) **10583A Footspacing Kit:** 152.4 mm (6 inch) Footspacing: 31.4 g (1.1 lbs) 101.6 mm (4 inch) Footspacing: 22.3 g (.78 lb) 50.8 mm (2 inch) Footspacing: 13.3 g (.47 lb) 10557A Turning Mirror Spacer: 3.7 g (.13 lb)	**10579A Straightness Adaptor:** 0.45 kg (1.0 lb) **Resolution Extender:** 0.82 kg (1.8 lbs) **10690A Straightness Reflector:** 0.50 kg (1.1 lbs) **Straightness Interferometer:** 0.23 kg (0.5 lb) **10691A Straightness Reflector:** 0.50 kg (1.1 lbs) **Straightness Interferometer:** 0.23 kg (0.5 lb) **10692B Optical Square:** 1.45 kg (3 lbs, 3 oz) **10693A Vertical Straightness Adaptor:** .379 kg (13.3 oz)
See back page.	See back page.

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Error Indication: Beam interruption, overspeed and tuning error. Display goes to zero and light flashes.
Reset: Pushbutton reset to zero.
Inputs: Automatic velocity of light compensation or manual VOL compensation.
- **Connector:** 50-pin Amphenol Blue Ribbon
- **Auxiliary:** Input for remote control of front panel functions such as Reset, Print, Select Modes (Normal, Smooth, X10, Velocity), Tuning or Beam Interrupt Indication).
- **Connector:** 24-pin Amphenol Blue Ribbon

Outputs: 1, 2, 4, 8 positive true BCD output for printer, desktop computer.
Connector: 50-pin Amphenol Blue Ribbon
Analog output with Error Plotting options.
Connector: 2 BNC types
Timed contact closure for automatic NC test advance, or periodic data recording applications.
Connector: Dual banana

Environmental (Operating):
- **Temperature:** 0° to 55°C (32° to 130°F)
- **Relative Humidity:** 0 to 95%
- **Vibration:** Tested to withstand 0.25 mm (0.010 inch) peak-to-peak excursion at 10-55 Hz 15 min. on each of 3 orthogonal axes.

Power Requirements: 115 to 230 volts ±10%; 50-60 Hz, 150W.
Overall Dimensions:
- **Display:** 141 mm high × 436 mm wide × 337 mm deep (5.53 in × 16.75 × 13.25 in)
- **Head:** 127 mm high × 178 mm wide × 526 mm long (5.00 in × 7.00 in × 20.70 in)

Weight:
- **Laser Display:** 10.8 kg (24 lbs)
- **Laser Head:** 7.8 kg (17 lbs)

Measurement Analysis . . .

10585A Metrology Program Package/Interface

The effectiveness of the HP 5526A Laser Measurement System can be greatly enhanced by the addition of an HP 9815 Desktop Computer and an HP Graphics Plotter.

Machine tool down time is reduced to the absolute minimum with the addition of these accessories. Machine geometry and positioning accuracy are measured, statistically verified and displayed in hard copy, graphical form. With the measurement data analyzed and presented this way, the causes of machine errors can be quickly determined, corrected and verified all in one session at the machine.

The HP Laser Measurement System including the Metrology Program, Desktop Computer and Graphics Plotter is a powerful tool for the most effective machine tool maintenance/repair effort.

Metrology Program Package. The 10585A Metrology Program Package is a set of metrology application programs developed specifically for the HP 5526A Laser Measurement System. Application areas covered by this software package include calibration of machine tool, measuring machine positioning accuracy and geometry (straightness, squareness and parallelism), plus surface plate flatness calibration.

No knowledge of programming is required to operate the system. The metrology program package has been designed for ease of use and can be run simply by following the step-by-step operating instructions as they appear on the Desktop Computer's display.

Since data is transferred directly from the Laser Display to the Desktop Computer, keyboard entry errors are avoided and substantial time is saved. The Desktop Computer can record data on a magnetic tape cartridge or on paper with its integral printer. Or it can output processed data to the HP 7225A Plotter.

The Metrology Program Package includes 10 programs developed especially for processing and plotting measurement data obtained with the 5526A Laser Measurement System.

The 10 metrology programs are stored on a single magnetic tape cartridge along with 59 extra files which can be used to store user generated data. Two Metrology Program cartridges are provided so that the user can keep a back-up set of programs. Accompanying the program package is a detailed operating manual. A brief description of each program follows.

Machine Tool Calibration

Positioning Accuracy The Metrology Program Package includes three programs for analyzing linear positioning errors:

Standard Error Analysis
Generalized Error Analysis
Statistical Error Analysis
(NMTBA recommended)

Standard Error Analysis This program is for calibration of positioning accuracy. The machine can either be

Automatic Measurement Analysis

stepped or moved at a constant feed rate along an axis. Measurement data are fed from the Laser Display to the Desktop Computer and sampled at each calibration increment. The sampling instruction can be a pulse or contact closure generated either by the machine being calibrated (e.g. by an encoder on the leadscrew) or by the Laser Display itself. The latter method is used for N/C machine where a plot rate is selected on the Laser Display front panel and an internal relay causes a calibration tape to advance the table to the next position. There is no separate input of command position since this is deduced from the measurement data. The maximum expected error can be any value selected by the operator.

The calculated errors are printed out by the Desktop Computer, and with the Plotter connected are plotted as shown in Figure 8.

With such a plot the performance of a machine tool positioning system can be rapidly evaluated. Cyclic errors, both fine and coarse, and slope errors are clearly visualized. The effects of adjustment can therefore be seen immediately, and expensive machine downtime kept to a minimum.

General Error Analysis This program is for evaluating positioning accuracy on the basis of pre-selected calibration points without the constraint of integral increments. Calibration increments, which could be selected on a statistical sampling basis, are stored in the Desktop Computer. As the measured position data is transferred from the Laser Display the error is calculated for each position, stored, and can be recorded as a function of axis position either in printed or graphical form. If statistical analysis is required the error-position data can be recorded on the Metrology Program cartridge and reentered as data for another program.

Statistical Error Analysis This program evaluates repeatability and backlash as well as positioning error. It also performs a statistical analysis. With the data from a number of traverses recorded by means of the Generalized Error Analysis program, a mean and 3-sigma (standard deviation) value at each command position is calculated, printed and/or plotted. An example of a statistical plot is shown in Figure 9.

Angular Error Analysis

This program enables the user to record pitch or yaw measurements as a function of position. It is similar to the standard error analysis program.

Straightness/Squareness/Parallelism

In addition to recording and printing the straightness readings generated by the Laser Measurement System, this program takes out the slope caused by misalignment between the axis of the "optical" straightedge" and the machine axis. At the completion of a straightness calibration traverse, the data are normalized and plotted with

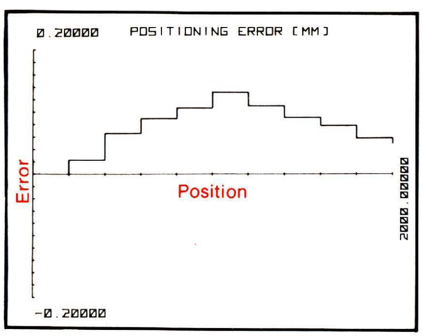


Figure 8. Positioning Error Plot Generated by the Standard Error Analysis Program.

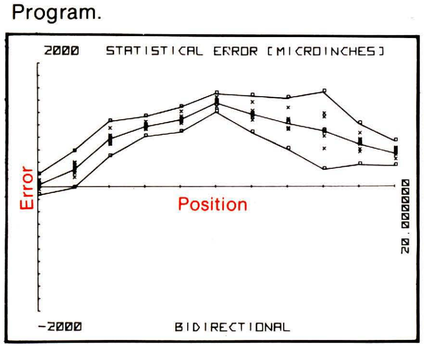


Figure 9. Mean and 3 Sigma Error Band Plotted by the Statistical Error Analysis Program.

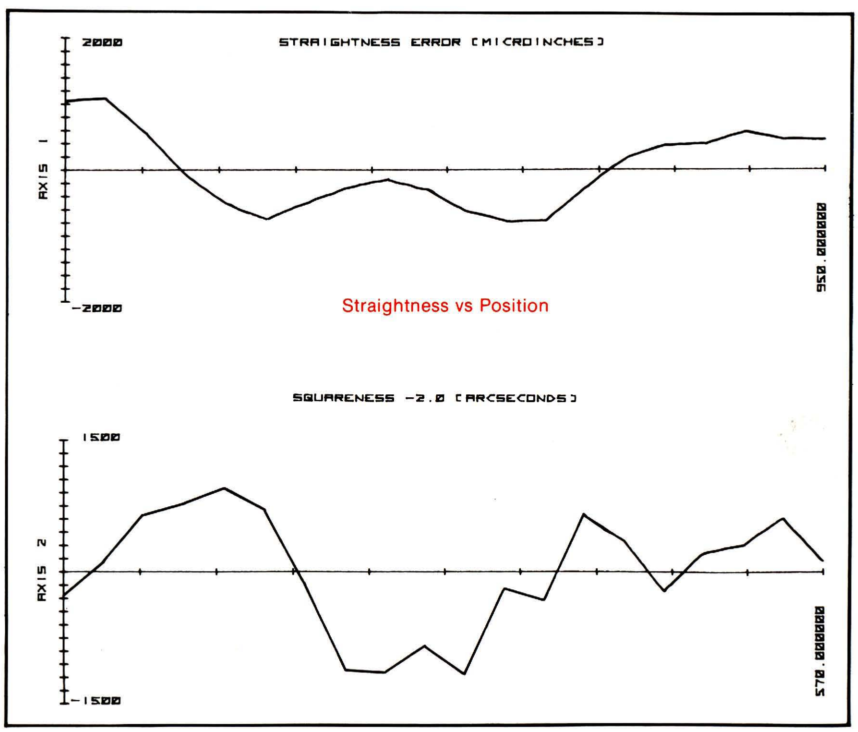


Figure 10. Plot depicting straightness of two orthogonal axes and the computation of their relative perpendicularity.

respect to a reference axis. This can be chosen to be either the line joining the end points or the least-squares best-fit to the data. As many passes as required can be made with the final plot being an average of all runs.

The program allows the recording of an entire second axis of data while storing the first line and its slope. When the second line has been plotted its slope is determined and the program can be instructed to compute the difference between the slopes to give either out-of-parallelism or out-of-perpendicularity as shown in Figure 10.

In addition to saving a significant amount of time by automating the recording and computing stages in a geometry evaluation, this program also saves set-up time. The program's ability to handle a very wide mismatch between the alignment of the "optical straightedge" axis and that of the machine means that fine adjustment of the "straightedge" axis can be virtually eliminated, thus saving valuable set-up time.

Surface Plate Calibration

The HP Laser Measurement System has established itself as an accurate and efficient instrument for measuring the flatness of surface plates and machine tool beds. The Laser Measurement System offers many advantages over autocollimators and precision levels.

It reads out directly in microinches or microns of surface height deviation which avoids the need to convert from an angular reading. Components mounted on the plate are passive; so no heat is produced which can distort the surface plate. The entire surface plate can be calibrated from one set-up of the laser head.

In addition the Desktop Computer and Plotter eliminate the tedious, time consuming task of converting the raw measurement data to a hard copy plot which shows the actual surface deviation from a true reference plane. This is accomplished in a few seconds.

Measurement data is transferred automatically from the Laser Display to the Desktop Computer as each data point is recorded by a remote switch. At the completion of each line the data is integrated, referenced to its end points, and printed out. Any apparent errors can be taken out by repeating the line. After all the data are in, a print-out of maximum elevation and closure errors will be made. A numerical plot as shown in Figure 11 can be obtained by reading in the numerical plot program. Alternatively the isometric plot program creates a "topographical" map as shown in Figure 12. If the plotter is not used, a print-out of the same data can be made with the Desktop Computer printer.

	Autocollimator and Desk Calculator	HP Laser Measurement System with Desktop Computer/Plotter
Set-up	5 mins.	10 mins.
Data Recording	2 hrs. 0 mins.	45 mins.
Calculations	1 hr. 30 mins.	1/2 min.
Preparation of Certification Chart	30 mins.	1 min.
	4 hrs. 5 mins.	56-1/2 mins.

Comparison of Time Required to Calibrate 6 ft. × 4 ft. Surface Plate

As the above comparison shows, for a typical size surface plate, the entire calibration from set-up to finished certification chart accomplished with the HP System takes only 1/4 the time required with an autocollimator and a conventional desk calculator; and you have the confidence that errors due to operator fatigue, misrecording of data or plate distortions have been eliminated.

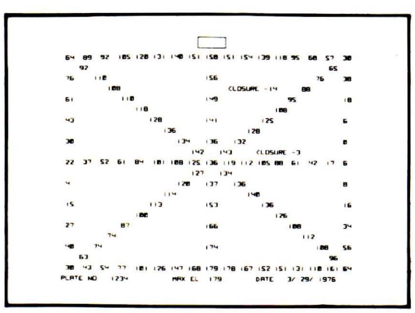


Figure 11. Numeric Surface Plate Plot

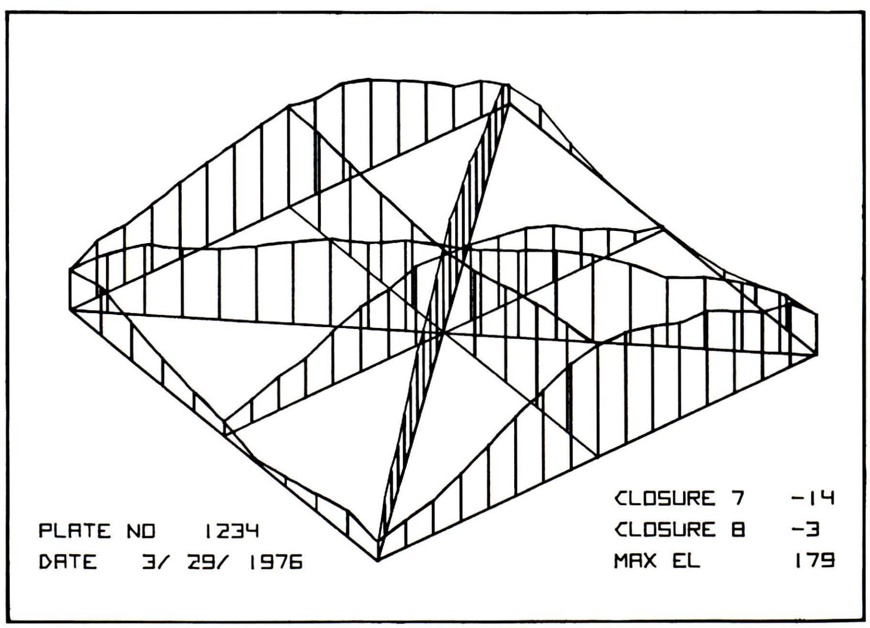


Figure 12. Isometric Surface Plate Plot

Miscellaneous Programs

Wavelength Compensation By entering ambient conditions and, if required, material temperature and coefficient of expansion, the user can obtain the wavelength compensation factor for entry into the 5505A Laser Display with this program. In some cases this can be a more convenient way of obtaining a compensation factor than looking it up in the operating manual.

Large Angle Corrections Users of the Angular Measurement accessories to the 5526A Laser Measurement System can improve the accuracy of angular measurement for large angles (greater than 3000 arc-seconds). This is accomplished by applying a correction factor to the Laser Display reading. The Desktop Computer takes the reading either directly from the Display or manually via the keyboard entry. The corrected reading is printed in radians, degrees, and/or arc-seconds.

Required Equipment

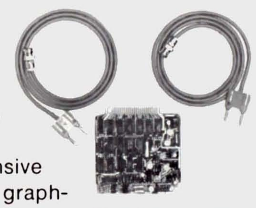
10585A	**Interface Metrology Program**
9815S	**Desktop Computer**
7225A	**Graphics Plotter with Opt. 001, 002, 003 or 004**
17600A	**Personality Module with Opt. 001 and 015**

Auxiliary Equipment

Recorders Model 5055A Digital Recorder with Opt 002 and C07 is direct-plug compatible to 5505A Laser Display. This instrument can provide a printout of the Laser Display reading at up to 10 lines per second.

Thermal Printer Model 5150A Thermal Printer with Opt 002 and 005 interfaces to 5505A Laser Display.

10555A Error Plotting Output
This option includes a plug-in circuit board and two cables to provide an inexpensive method of graphically recording positioning errors as a function of command position, during the calibration traverse, without any external computation device. Downtime is minimized and external data processing is eliminated. With the error information in graphical form, wear patterns, cyclic errors, and other characteristics can be readily distinguished as shown in Figure 13.



Upon receipt of a pulse or contact closure, generated within the Laser Display, or provided by the operator, the measurement value is sampled and split into two parts; command position (most significant digits) and error (contained in the least significant digits). The assumption is made that maximum error does not exceed more than half the minimum calibration interval.

The error and command values are outputted in analog form at two rear panel terminals for connection to an XY recorder, such as HP Model 7035B or 7035B Opt 001 Metric XY Recorder.

10586A Interface Cable
The 10586A Cable allows BCD data from the 5505A Laser Display to be sent to the 9825, 9835 and 9845 Desktop Computers. The data received by the Desktop Computers can be processed and output to various devices including HP printers and plotters such as the HP 7225A Graphics Plotter, the HP 7245A Plotter/Printer and the HP 9872B/S Four Color Plotter.

No operating software is supplied. Contact your Hewlett-Packard sales representative for availability of user contributed metrology programs.

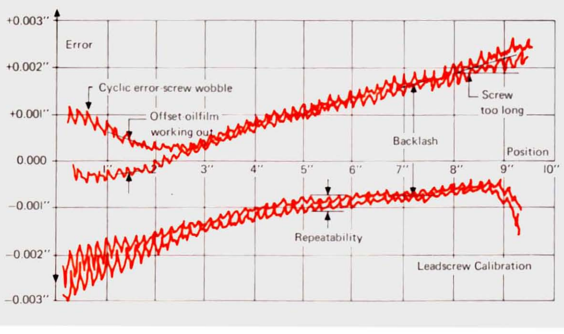


Figure 13. Two out and back *(top and bottom)* error plots of a milling machine leadscrew clearly show the various sources of error.

10563A Material Temperature Sensor

5510A Automatic Compensator

Automatic Compensation

In a typical measurement environment there will be constant changes in the temperature, pressure and humidity which in turn will change the wavelength of the laser light in air. This will affect the accuracy of the measurement since it is dependent on knowing the laser wavelength precisely.

To ensure accurate readings, the HP Laser Measurement System offers the choice between manual and automatic compensation for wavelength changes. Thumbwheel switches are provided on the front panel of the 5505A Laser Display for inputting in a compensation factor derived from tables included with the Laser Display.

The Model 5510A Automatic Compensator takes over the task of inputting in the compensation factor completely. It is equipped with rugged sensors which can measure air temperature, pressure and humidity. The Automatic Compensator provides accurate, continuously updated compensation data to the 5505A Laser Display.
In addition, up to three 10563A Material Temperature Sensors may be ordered for monitoring machine or workpiece temperature so that dimensions are always corrected to the standard reference temperature of 20°C (68°F), regardless of the temperature during measurement.
All that is required of the operator is the dialing in of the thermal coefficient of expansion of the material before taking measurements.

As well as being very simple to operate, the 5510A offers unmatched user confidence as a result of on-line sensor read-out. The reading of any sensor may be shown on the 5505A Laser Display, even while the measurement is in progress. The displacement information is constantly being updated internally while the display is shared. This feature is particularly useful for making a record of conditions along with the measurement data.

The Air/Humidity Sensor (included with the HP 5510A) and the HP 10563A Material Temperature Sensor are attached to cables for remote location. They are self-contained calibrated units so that they may be interchanged among instruments.

One HP 5510A Automatic Compensator and up to three 10563A Material Temperature Sensors may be used with the HP 5510A Automatic Compensator. The readings from multiple material sensors are automatically averaged by the 5510A. This is especially useful for making measurements on large structure which may have temperature gradients.

Since material temperature correction has the largest potential effect on measurement accuracy, an optional higher accuracy material temperature sensor is available as HP 10563A Opt 001. It has an accuracy of ±0.028°C (±0.05°F) over a reduced range compared with ±0.1°C (±0.2°F) for the standard 10563A.

Specifications

5510A Automatic Compensator
Air Sensor:
Temperature Accuracy: ±0.1°C (±0.2°F)
Range: 13-40°C (55-105°F)
Pressure Sensor:
Pressure Accuracy: 0.75 mm Hg (±0.03 in Hg)
Range: 560-790 mm Hg (22-31 in Hg)
Humidity Sensor:
Humidity Accuracy: ±10% RH
Range: 20-100% RH

10563A
Material Temperature Sensor
Thermistor type. Mounted in remote, oil immersible "button" with magnetic base. One required per 5510A Automatic Compensator. Up to 3 may be used.
Range: 13-40°C (55-105°F)
Maximum Sensor Error: ±0.1°C (±0.2°F)
Total measurement accuracy depends on knowledge of material's temperature coefficient of expansion.

10563A
Opt 001 High Accuracy Material Temperature Sensor:
Range: 19.0-24.5°C (66-76°F)
Maximum Sensor Error: ±0.028°C (±0.05°F)

Automatic Compensation (worst case only):
For air temperature within range 20-30°C (68-85°F):
Metric Units: ±1.3 ppm ±2 counts in last digit
Inch Units: ±1.3 ppm ±1 count in last digit
For air temperature within range 13-40°C (55-105°F):
Metric Units: ±1.5 ppm ±2 counts in last digit
Inch Units: ±1.5 ppm ±1 count in last digit

General
Total Compensation Factor Range: ±700 ppm. Warning light indicates out of range condition
Coefficient of Expansion Range: ±29.9 ppm/°C or °F
Sensor Read-Out (with 5505A Laser Display): All sensor values (in English or Metric units), and compensation numbers with and without material component. In SCAN mode all parameters are read out at 2 per second
Environmental (operating):
Temperature: 0-55°C (32-130°F)
Humidity: 0-95% RH
Vibration: 0.25 mm (0.01 in) peak-to-peak at 10-55 Hz for 15 min. on each axis.
Power Requirement: Power is supplied by 5505A Laser Display via connector cable.
Dimensions: 159 mm high × 197 mm wide × 280 mm deep (6¼ in × 7¾ in × 11 in) without sensors. With sensors connected depth is increased by 76 mm (3 in).
Weight: 4.9 kg (10.8 lbs)

10580A Laser Tripod

All the interferometers in the Laser Measurement System are remotely locatable from the Laser Head for greater accuracy and easier fixturing. This enables the Laser Head to be mounted away from the measurement setup which eliminates the heat source.

The Model 10580A Laser Tripod is designed especially for this purpose, offering benefits of easier set-up and more rapid alignment. A mounting plate, equipped with quick release clamps, can be adjusted for height, rotation, and lateral position. Tilt adjustment is by the rear foot of the Laser Head itself. The tripod is collapsible and portable yet covers a wide range, from 825 mm (32 ½ inches) to 1640 mm (64 ¾ inches).

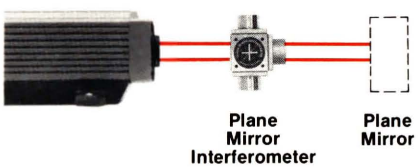
Specifications
Dimensions: See back page.
Weight (Net): 14 kg (31 lbs)

10552A Resolution Extender

The 10552A Resolution Extender provides the 5526A Laser Measurement System with an additional digit of resolution. The Resolution Extender is a small module connected between the Laser Head and the Display. With the extender inserted, the display operates in all modes including X10 and velocity.

Specifications
The 10552A Resolution Extender works with Linear and Angular Interferometers only. It is not compatible with Plane Mirror, Single Beam or Straightness Interferometers.
Maximum Measuring Velocity: 1.5 m/min (1 inch/sec)
Weight: 0.9 kg (2 lbs)
Size: 3.8 cm high × 13 cm wide × 15.1 cm deep (1 1/2 inch × 5 1/8 inch × 6 inch)

Plane Mirror Interferometer



The Plane Mirror Interferometer allows the user to measure the displacement of a plane mirror in place of the retroreflector.

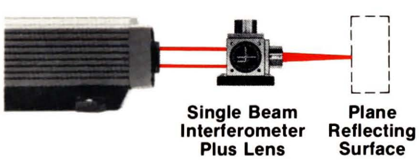
Its unique optical design has high tolerance to angular misalignment of the plane mirror which greatly simplifies mirror alignment.

The primary application of the Plane Mirror Interferometer is as a position transducer for XY positioning stages. It allows mounting simplicity and accuracy not achievable with any other optical arrangement.

The Plane Mirror Interferometer consists of a 10565B Remote Interferometer, a 10556A Retroreflector and a 10581A Plane Mirror Converter.

Specifications
Plane Mirror Requirements:
Flatness: Flat to within 1/8 wavelength (3 microinches) over any 20 mm (0.8 in) dimension.
Surface Finish: Metal 0.0025-0.0076 μm (0.1-0.3 microinch) arithmetic average. Optical 80-40.
Maximum Angular Misalignment: Depends on distance between interferometer and mirror plane. Typical values are:
±25 arc-minutes for 254 mm (10 in)
±15 arc-minutes for 508 mm (20 in)
±5 arc-minutes for 1270 mm (50 in)

10562A Single Beam Interferometer and Opt 001 Non-Contact Conversion Kit



For those applications where the mass or size of a cube-corner retroreflector precludes the use of the 10565B Remote Interferometer, the Single Beam Interferometer is the solution. Since it can measure displacement with a single laser beam reflected back on itself, the beam can be directed into the apex of a small retroreflector.

The primary application is in using a lens to focus the beam on a reflective surface, by which means a non-contact measurement can be made. With the appropriate lens selected, displacement of the reflective surface is measured. Alignment and surface finish requirements are relaxed by using this optical arrangement called a "cat's eye".

The 10562A Opt 001 Non-Contact Conversion Kit is available for this purpose. It includes three lenses with focal lengths of 127, 254 and 762 mm (5, 10 and 30 inches).

Specifications
Reflector Requirements (with focusing optics):
Flatness: Flat to within 0.25 μm (10 microinches) over the spot diameter of the lens being used. (See below.)
Surface Finish: Metal 0.0025 -0.0076 μm (0.1-0.3 microinch) arithmetic average. Optical 80-40.

Non-Contact Conversion Kit

Focal Length	127 mm (5 in)	254 mm (10 in)	762mm (30 in)
Spot Diameter	0.01mm (0.0004 in)	0.02mm (0.008 in)	0.06mm (0.024 in)
Displacement Range	1.0mm (0.040 in)	4.0mm (0.200 in)	38.0mm (1.500 in)
Maximum Misalignment of Mirror to Beam Axis	±52 arc-min	±25 arc-min	±9 arc-min

Principle of Operation

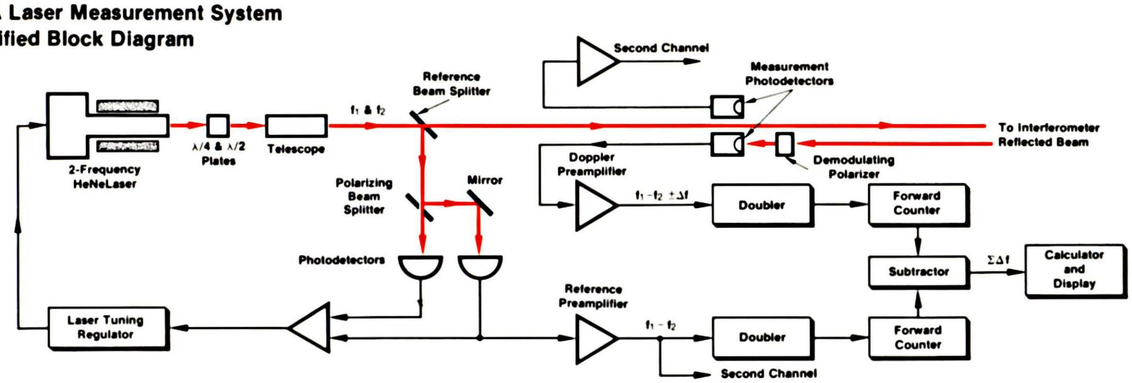
The low-power Helium-Neon laser in the 5526A Laser Measurement System emits a coherent light beam composed of two slightly different optical frequencies f_1 and f_2, of opposite circular polarizations. After conversion to orthogonal linear polarizations the beam is expanded and collimated, then directed to the reference beam-splitter where a small fraction of both frequencies is split off.

This portion of the beam is used both to generate a reference frequency and to provide an error signal to the laser cavity tuning servo. The difference in the DC levels of f_1 and f_2 is used for tuning while the AC component of the difference between f_1 and f_2 (about 1.8 MHz) is used for reference and goes to a counter in the Laser Display.

The major portion of the beam passes out of the Laser Head to an interferometer. All HP interferometers measure relative displacement of two retroreflectors by splitting the beam into f_1 and f_2, directing them to two retroreflectors, and returning the resultant signals to a photodetector in the Laser Head. Relative motion between the retroreflectors causes a difference in the return frequencies, thus creating a difference between the frequency seen by the measurement photodetector and that seen by the reference photodetector. This difference is monitored by a subtractor and accumulated in a fringe-count register.

A digital calculator samples the accumulated value every 5 msec and performs a two-stage multiplication, one for refractive index correction and the other for conversion to inches or millimetres. The resulting value updates the display.

5526A Laser Measurement System Simplified Block Diagram

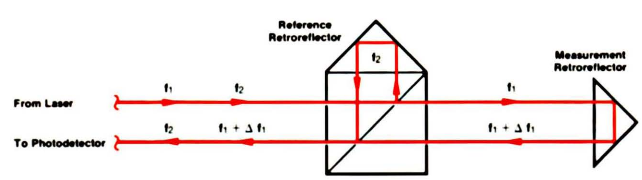


INTERFEROMETERS

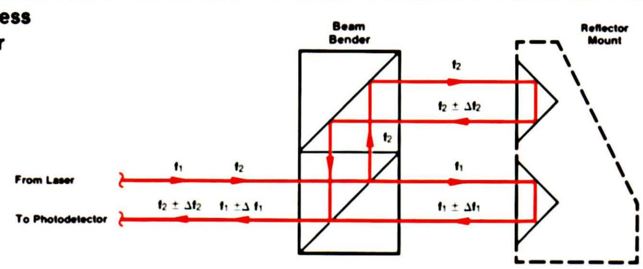
Linear. The beam exiting from the Laser Head is split at the surface of a polarizing beam-splitter, with one frequency reflected to the reference retroreflector mounted on the housing. The other frequency is transmitted to the measurement retroflector. Both frequencies are reflected back along a common axis to the photodetector block in the Laser Head, one of which includes a Doppler frequency shift whenever the measurement retroreflector moves. Since their polarizations are orthogonal to each other, they do not interfere to form fringes until the beam reaches the demodulating polarizer mounted in front of the photodetector.

Angular/Flatness. A 45° mirror is mounted in place of the reference retroreflector so that f_1 and f_2 are sent out parallel. Angular displacement of the retroreflector mount causes a differential Doppler shift in the returned frequencies. It is not affected by axial displacement. The accumulated fringe counts are proportional to the sine of the angular displacement.

Linear Interferometer



Angular/Flatness Interferometer



Straightness Interferometer. The two-frequency beam exiting from the Laser Head is transmitted through the Wollaston prism interferometer. Because the composite refractive index of the prism is different for the two planes of polarization which distinguish f_1 and f_2, f_1 and f_2 exit with a small included angle.

They are reflected back by two plane mirrors rigidly mounted at an included angle precisely matched to that of the Wollaston prism interferometer. f_1 and f_2 therefore recombine within the prism. The combined beam is returned coaxially with the exit beam to the partial mirror in the Straightness Adaptor. The majority of this returning signal is reflected down to a mirror which reflects the return beam back into the lower aperture of the Laser Head and thus to a demodulating polarizer and photodetector.

The interferometer measures relative lateral displacement between the interferometer and the reflecting mirror axis. Whether the measurement will be in a horizontal or vertical plane depends on the orientation of the mirrors and the prism within its mount.

Relative lateral displacement between the prism and the mirrors affects the difference in optical path lengths between the two beams causing a difference in accumulated fringe counts. Movement of the mirror assembly with respect to the beams causes a lengthening in the beam from the side to which the mirror assembly moves, and a shortening on the opposite beam. For movement of the interferometer with respect to the axis of the mirror assembly, there is an optical path length change within the prism proportional to the difference in the refractive indices specific to each plane of polarization. In either case, for a relative lateral translation, x, the fringe counts accumulated will be given by $2x \sin \theta/2$, where θ is the included angle between the beams. However, if the beam moves with respect to the mirror axes, any path length change in the air space is balanced by a compensating optical path length difference within the prism. Thus the device is sensitive to spatial deviations of the laser beam.

Small pitch, yaw, or roll motions of the Interferometer do not create a path difference and therefore do not affect the measurement accuracy.

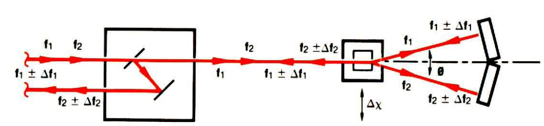
To give a correct readout at the display, the fringe counts must be multiplied by the reciprocal of $2 \sin \theta/2$, which for the value of θ used is 36. An electronic Resolution Extender is included to take care of this. θ is about 1½ degrees for the Short-Range Interferometer, and one tenth that for the Long-Range version.

Plane Mirror Interferometer. The beam entering the interferometer is split into f_1 and f_2 with f_2 returning to the Laser Head after retroreflection by the reference cube-corner, as in the Linear Interferometer. f_1 is transmitted out to the plane reflector and is reflected back on itself. The Converter causes the polarization of the return frequency to be rotated through 90° so that $f_1 \pm \Delta f$ 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° so it is now transmitted back to the photodetector. Resolution doubling is inherent because of the double Doppler shift but the 5505A Laser Display is designed to remove the doubler in the output from the Doppler preamplifier, thus correcting the displayed resolution.

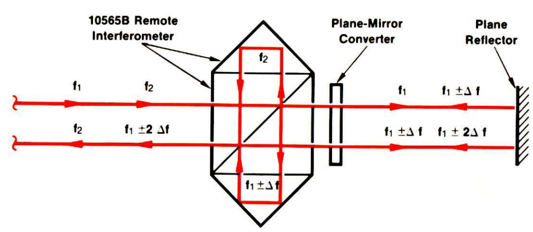
Any tilting of the plane reflector relative to the beam axis results only in an offset of the return, not in a tilt, since tilting of the reflected beams is exactly compensated by the second reflection.

Single Beam Interferometer. A polarizing beam-splitter reflects f_2 to the reference retroreflector and transmits f_1 to the surface whose displacement is being measured. Since both beams leaving the beam-splitter pass thru a quarter-waveplate the returning polarizations are rotated thru 90°. This causes f_2 to be transmitted and $f_1 \pm \Delta f$ to be reflected so that they are returned coaxially to the Laser Head by the beam-bending mirror.

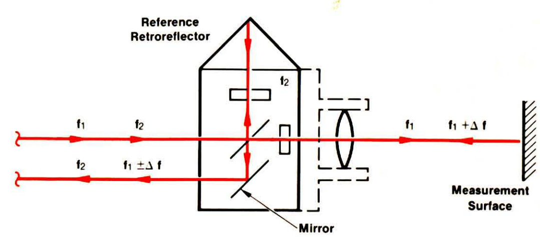
Straightness Interferometer

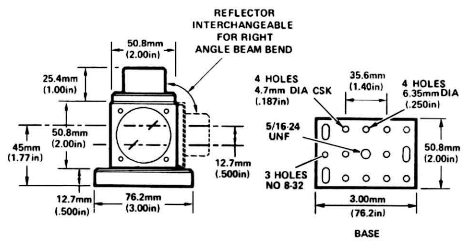


Plane Mirror Interferometer

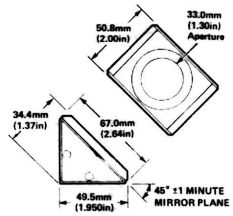


Single Beam Interferometer

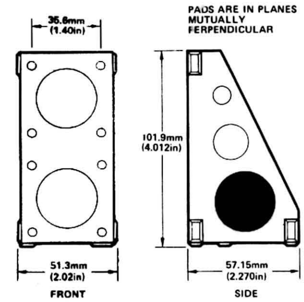




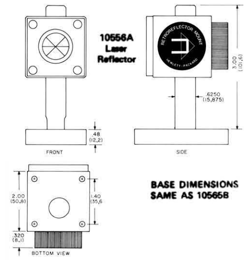
10565B REMOTE INTERFEROMETER



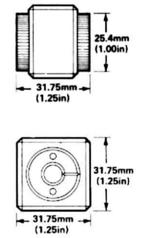
10557A TURNING MIRROR



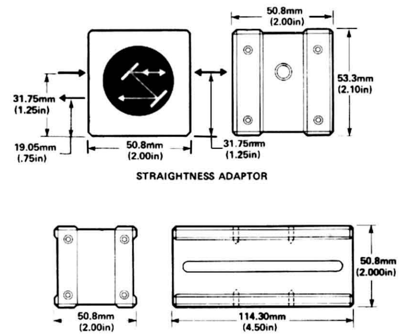
10559A REFLECTOR MOUNT



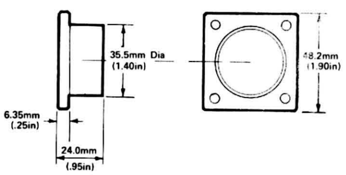
10550B LASER REFLECTOR AND MOUNT



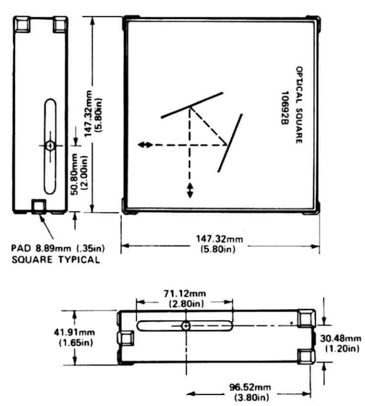
STRAIGHTNESS INTERFEROMETER

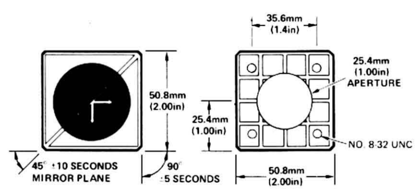


STRAIGHTNESS REFLECTOR

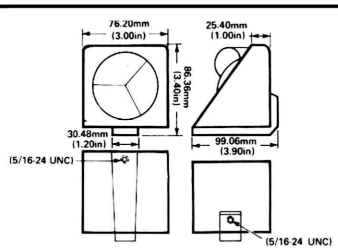


10581A PLANE MIRROR CONVERTER



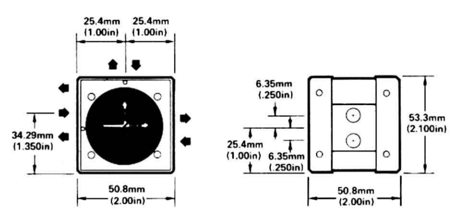


10581A BEAM BENDER

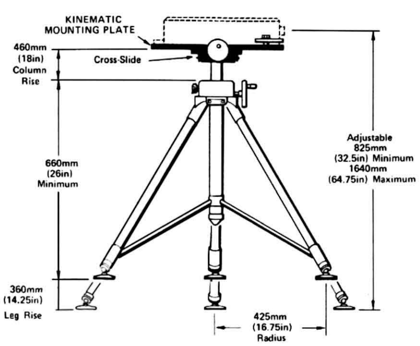


10693A VERTICAL STRAIGHTNESS ADAPTOR

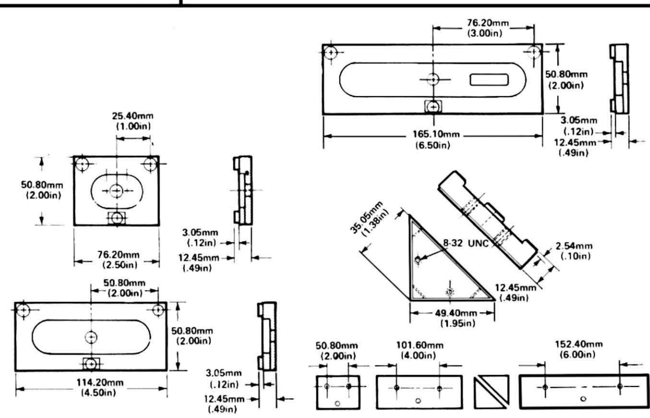
10692B OPTICAL SQUARE



10567A BEAM SPLITTER



10580A LASER TRIPOD



10583A FOOTSPACING KIT

02-5952-7134

PRINTED IN U.S.A.