Flatness measurement

User guide

This manual is available in English only

Issue 5.1

Procedure for performing flatness measurement

Flatness measurements are performed to check the flatness of CMM tables and surface plates. It determines whether any significant peaks or troughs exist and quantifies them. If these errors are significant then remedial work, such as lapping, may be required.

IMPORTANT - please read the SAFETY section before proceeding.

To understand the basic principles and techniques of flatness measurement refer to:

- The principles of flatness measurement.
- Standard methods of assessing flatness.

To perform flatness measurements using the Moody method, carry out the following steps:

- Prepare the surface plate for flatness measurement.
- Set up the flatness data capture software.
- Set up the laser and optics.
- Align the laser beam along a measurement line.
- Capture data for the measurement line.

- Set up and measure the other seven measurement lines.
- Analyse the captured flatness data. Inspect the data for measurement errors as discussed in Factors affecting accuracy of flatness measurement

Specifications - Gives a full specification for flatness measurement accuracy.

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Procedure for performing flatness measurement - Issue 5.1
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Flatness measurement kit

Figure 1 - Flatness measurement kit

The flatness measurement kit is used to measure the flatness of surface plates and granite tables. The flatness measurement kit comprises:

- two turning mirrors
- three flatness bases - 50 mm (1.97 in) foot spacing
  - 100 mm (3.94 in) foot spacing
  - 150 mm (5.91 in) foot spacing

The angular measurement optics are also required where the angular interferometer is attached to a turning mirror and the angular reflector is attached on top of the selected flatness base.

Each flatness base is supported on three feet of circular cross-section. The distance between the centres of the two feet, underneath the flatness base's white centre line, defines the foot spacing.

The three flatness bases enable measurements to be made at the three standard foot-spacings offered by the measurement software. (**Note:** non-standard, customer-defined foot-spacings can also be used.) The size of the base used depends on the size of the surface to be measured and the required number of points to be taken.

The flatness turning mirrors allow the laser beam to be directed along any line of the surface plate without having to move the laser. The mirrors can be rotated about their vertical axes and also tilted by adjusting the small thumbscrew on the baseplate behind the mirror.

You will also need a straight edge as long as the longest measurement line (this is not supplied in the kit because the length required will vary depending on the specific application). The straight edge should be thicker than 1 mm (0.04 in) so that contact is made along the sides of the flatness base rather than against the small ground feet on the underside of the base. If it is not practical to use a single straight edge, two or more may be used together, provided that they are carefully aligned.

For details of how to perform flatness measurements using this kit, refer to the flatness measurements section.

See the dimensions and weights section for the dimensions of the flatness measurement optics.

`Flatness measurement kit - Issue 5.1`

Principle of flatness measurement

The flatness measurement kit is used to measure flatness. The angular interferometer is attached to the turning mirror and the angular reflector is attached on top of the selected flatness base. The angular interferometer is placed in the path between the laser head and the angular reflector.

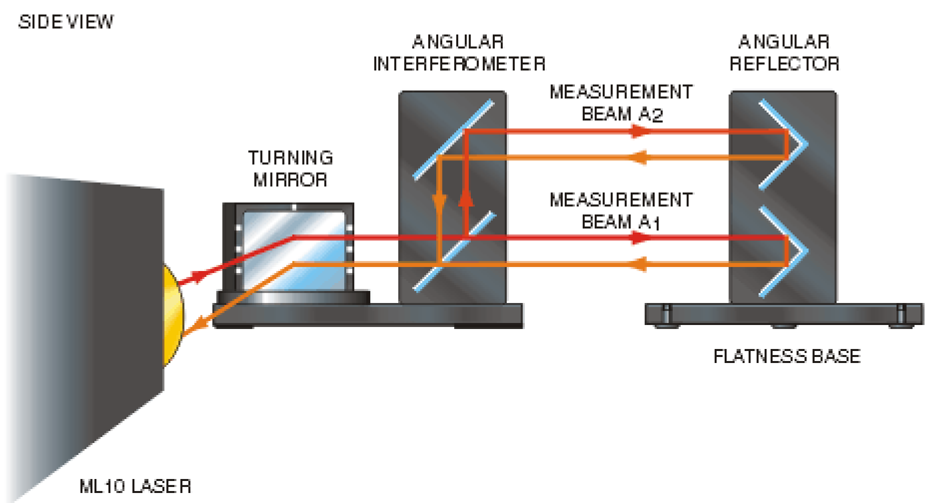

Figure 1 - Principle of measurement

The laser beam is split into two by the beam-splitter inside the angular interferometer. One part of the beam (the measurement beam A_1) passes straight through the interferometer and is reflected by one of the twin reflectors of the angular reflector back through the interferometer and into the laser head. The other beam (measurement beam A_2) passes through the periscope part of the angular interferometer to the second reflector from where it returns through the interferometer and into the laser head.

An angular measurement is produced by comparing the path difference between the beams A_1 and A_2, (i.e. the measurement is independent of the distance between the laser and the interferometer). The 'flatness reading' displayed by the software is the incremental height between the 'front' and 'back' feet of the flatness baseplate on which the angular reflector is fitted. This incremental height is calculated from the angular measurement and a knowledge of the distance between the centres of the front and back feet of the flatness baseplate. This distance, termed 'the foot-spacing', must be entered into the calibration software before measurement starts.

For each measurement line (see Standard methods for assessing flatness), the angular interferometer (mounted on the flatness turning mirror) stays stationary, while the reflector (mounted on a flatness base) moves along the line in incremental steps defined by the foot-spacing.

A flatness measurement is carried out by taking a series of incremental height readings as the angular reflector is moved along the measurement path.

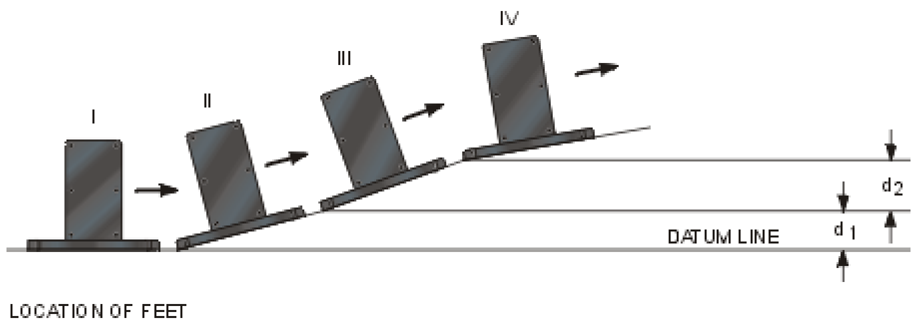

Figure 2 - Incremental measurements drawing changes

In Figure 2 above:

- Position I is the initial position at which the interferometer reading is normally datumed.
- Position II is one foot-spacing beyond Position I. The interferometer reading will be the incremental distance d_1, which is the difference in 'height' (with respect to the datum line) of the front and back feet of the flatness baseplate.
- Position III is one foot-spacing beyond Position II. The interferometer reading will be d_2, i.e. the difference in height between the front and back feet of the baseplate in its new position.
- Similarly, the reading at Position IV will be d_3, and so on for all subsequent positions on the measurement line.
- The actual flatness of the measurement line will be the algebraic sum of the reading d_1, d_2 etc (plus the reading at the 'datum' position (I) if it had *not* been zeroed).

Note: Environmental compensation is not required when taking flatness measurements, as the difference in path lengths between the two beams is so small that the error due to environmental effects is negligible.

`Principle of flatness measurement - Issue 5.1`

Standard methods for assessing flatness

To measure the flatness of a surface, a number of measurement lines need to be taken over the surface. There are two standard methods of carrying out flatness measurements:

- Moody method
- Grid method

The flatness of a surface can be defined as the separation of two planes which are parallel to the general trajectory of the surface and which *just* enclose the measured surface as shown in Figure 1.

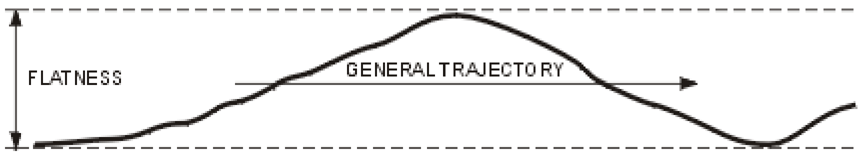

Figure 1 - Flatness specification

Flatness deviations for a surface plate of a known size can be compared with permitted deviations in national standards.

Moody method

With the Moody method, measurement is restricted to the eight prescribed lines as shown in Figure 2.

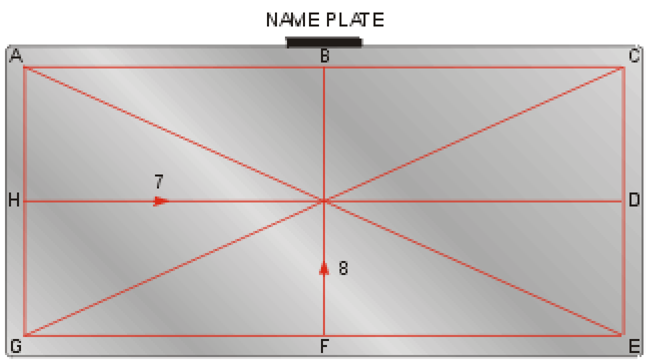

Figure 2 - Moody map of surface plate

The Moody method was first proposed by J.C. Moody in 1955 and has subsequently achieved wide acceptance. The method provides a relatively quick method of calibrating a surface plate, with the results being presented as a contour plot along the eight measurement lines tested, in a format acceptable for certification.

This method does have one disadvantage - *all* of the points on *all* of the eight lines must be measured and plotted. This can cause problems in defining a foot-spacing which will meet this requirement, particularly on slotted tables/surfaces where the position of one or more slots may coincide with the required position of one of the feet of the flatness base.

Grid and half grid method

With the Grid method, any number of lines may be taken in two orthogonal directions across the surface as shown in Figure 3.

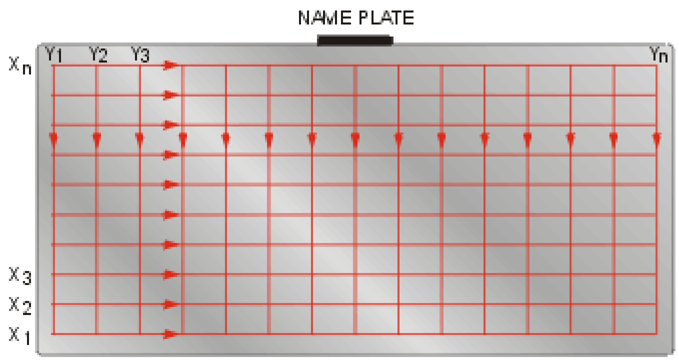

Figure 3 - Grid map of surface plate

With the Grid method, whilst the incremental nature of the measurement technique requires that all points on a given line are measured, it is not necessary to take measurements on all lines. This allows the measurement lines to be configured to avoid 'obstructions' (e.g. slots) or to provide greater detail in a given area.

The Half-grid method as shown in Figure 4 is a special case of the grid method where a number of measurement lines are taken in one direction (e.g. the X-axis), but only the perimeter lines are used for the orthogonal direction.

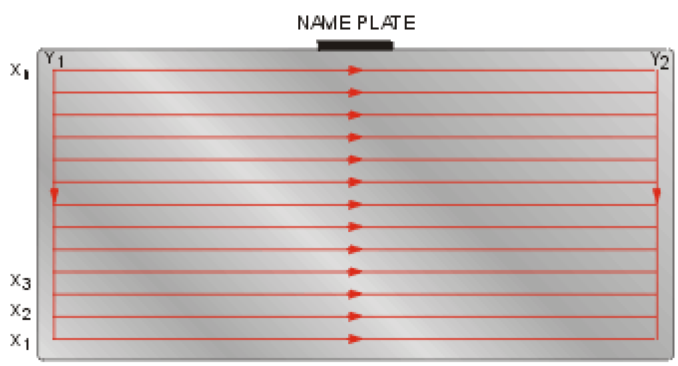

Figure 4 - Half-grid map of surface plate

A disadvantage with both grid methods is that they require a reference plane to be defined. An alternative technique such as the Moody method is needed to define this reference plane.

`Standard methods for assessing flatness - Issue 5.1`

Flatness measurement preparation and set-up

This section discusses the set-up for a Moody method flatness measurement. Similar principles can be used for the Grid method.

Preparation of the surface plate

1. Before calibration, the surface plate should be cleaned thoroughly and left to reach thermal equilibrium with the surroundings. A 'map' of the measurement lines should be marked on the surface plate itself with lead pencil or chalk.

2. All markings made on the surface plate should be offset from the measurement line by either 8.5 mm (0.33 in) or 41.5 mm (16.33 in), these being the distances from the longitudinal edges of the baseplates to the centre line through the front and back feet as shown in Figure 1. Care should be taken *not* to mark the table where a flatness foot placing will occur, as this may cause measurement errors.

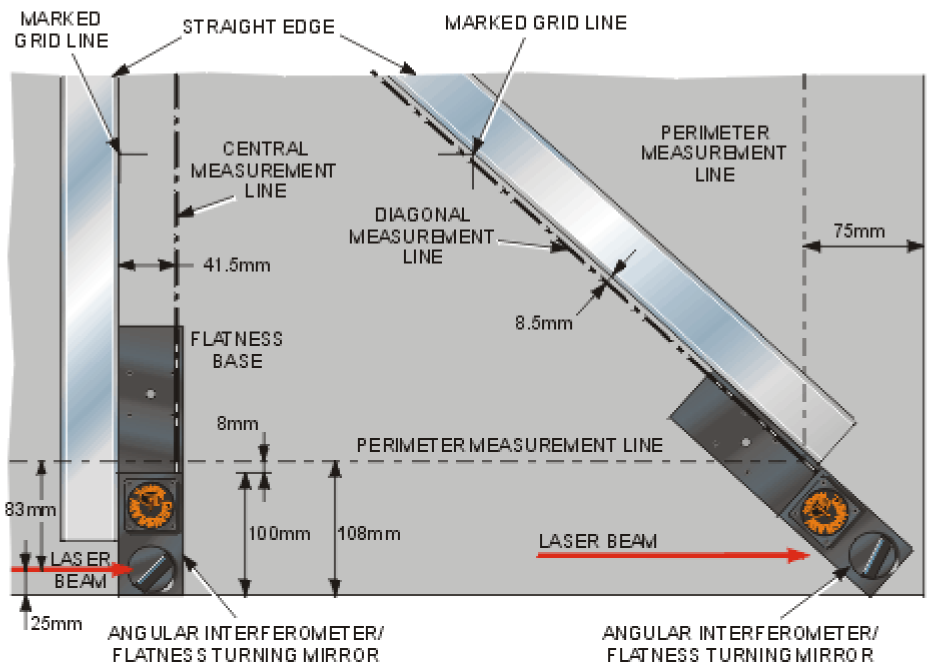

Figure 1 - Location of perimeter lines

3. To allow the placement of the turning mirror, the perimeter measurement lines should be at least 108 mm (4.25 in) from the edge of the surface plate on the side that will be parallel to the laser beam, and at least 75 mm (3 in) from the other three edges as shown in Figure 1.

4. The length of each measurement line should be an integral multiple of the foot-spacing selected. This places a constraint on the surface area which can be measured and it may not be possible to 'map' the whole of the surface area. When using the Moody method, the constraint is more severe as this requirement applies to the two diagonals as well as the orthogonal axes. In practice, acceptable closure errors can normally be achieved if the length of the diagonal meets this requirement to within 1% of the foot-spacing. The Renishaw data capture software provides assistance in selecting a suitable number of target points (and hence an effective table size) for any given foot-spacing and table size.

   Flatness data capture software

Set-up of laser and optics

1. Mount the ML10 laser on the tripod remote from the surface plate. Ensure the laser is level. Once positioned, the laser should not be moved.

2. Align the laser head parallel to the surface plate and to a perimeter line, with the beam at least 83 mm (3.25 in) from the perimeter line and 25 mm (1 in) from the edge of the surface plate as shown in Figure 2.

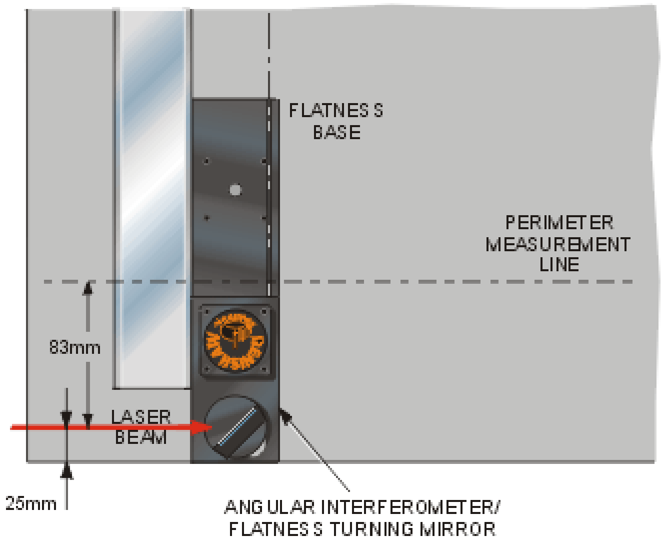

Figure 2

3. So that all measurement lines can be taken without moving the ML10 laser, mount the angular interferometer, as shown in Figure 3, on the base of a flatness turning mirror. Mount the angular interferometer so that the side with the single optical aperture is facing the mirror and the side with two optical apertures is facing the angular reflector. This is used for all measurement lines. A second flatness turning mirror is used for those measurement lines which require a further deviation of the beam, see Figures 4, 5, 6, 7 and 11.

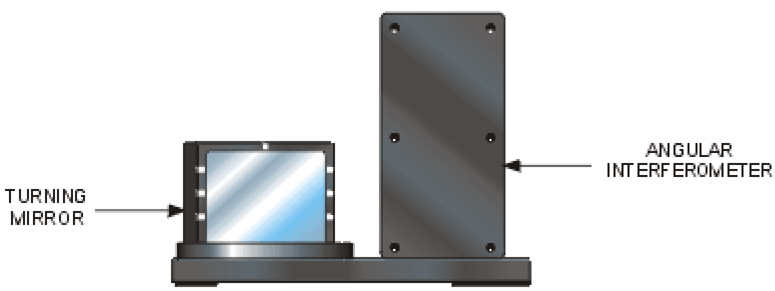

Figure 3

Measurement line set-up and capture

Perform a measurement along each of the measurement lines as shown below:

Diagonal EA
Perimeter line CA
Centre line DH
Perimeter line EG
Perimeter line AG
Centre line BF
Perimeter line CE
Diagonal GC

- For each measurement line, align the optics over the entire length of travel.
- Capture data for that measurement line.

Minimise measurement errors as discussed in factors affecting accuracy of flatness measurements.

Moody measurement line configurations

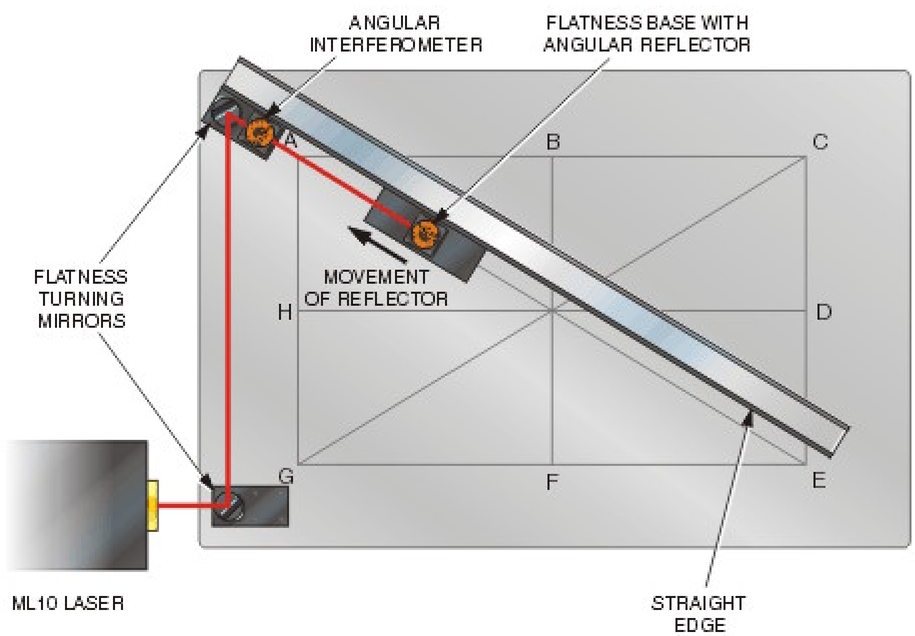

Figure 4 - Typical Moody measurement routine - diagonal EA

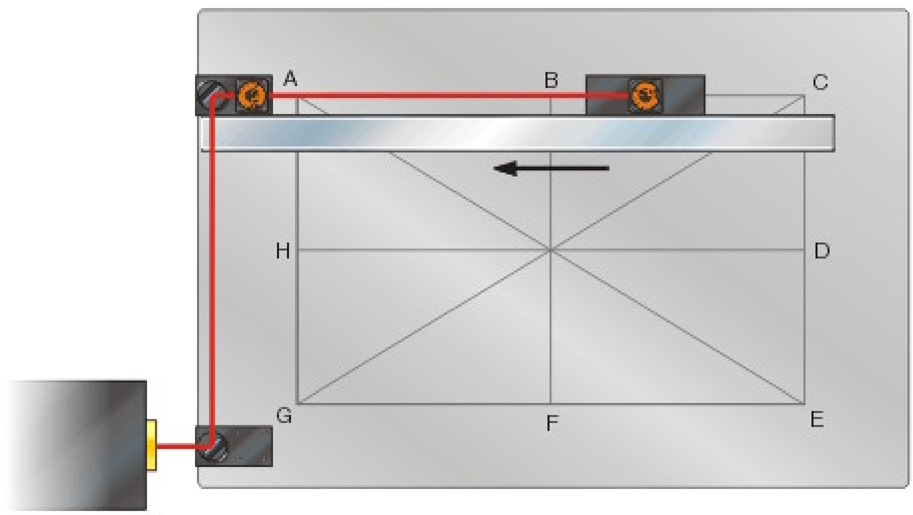

Figure 5 - Typical Moody measurement routine - perimeter line CA

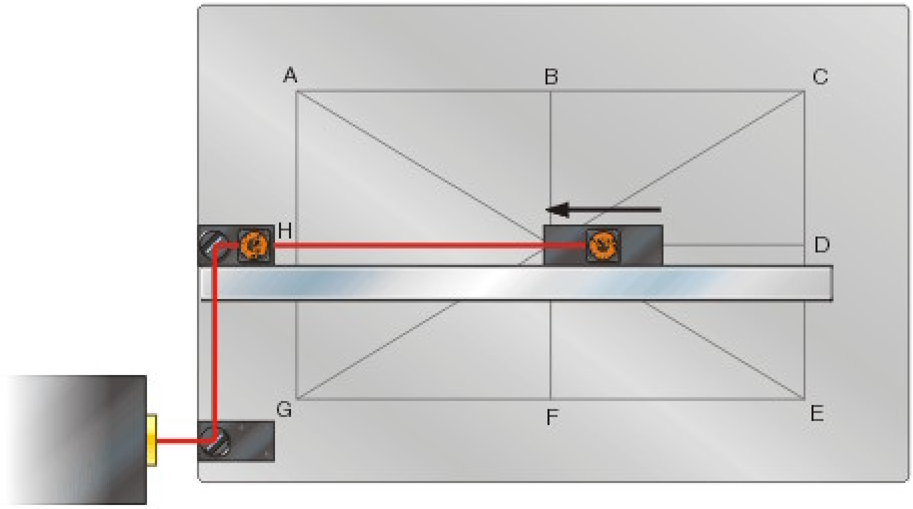

Figure 6 - Typical Moody measurement routine - centre line DH

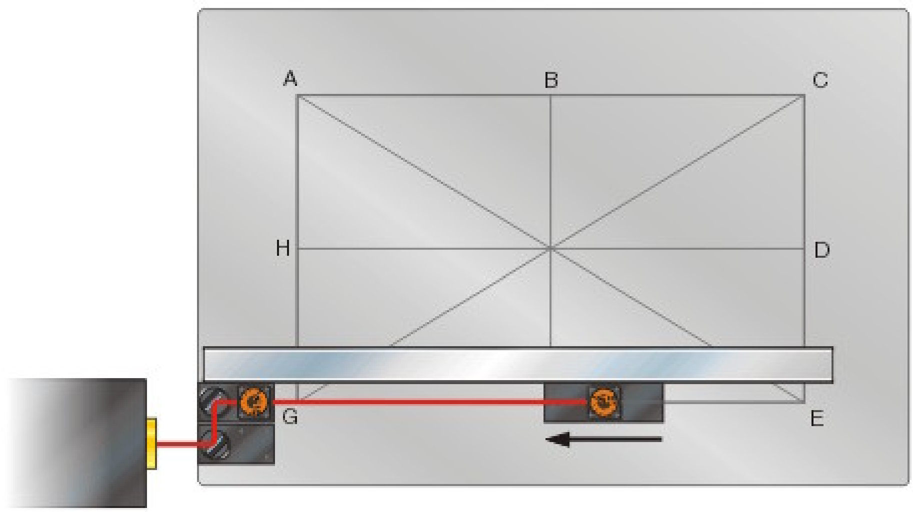

Figure 7 - Typical Moody measurement routine - perimeter line EG

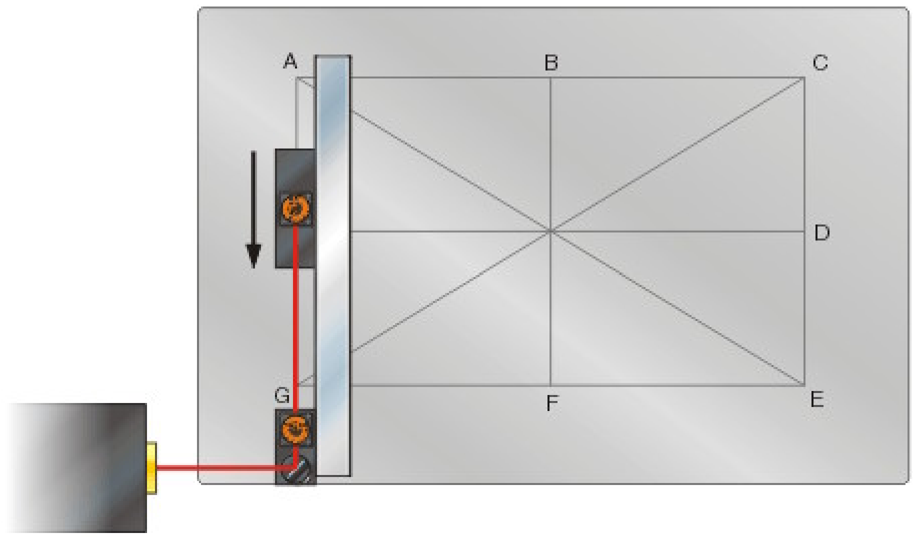

Figure 8 - Typical Moody measurement routine - perimeter line AG

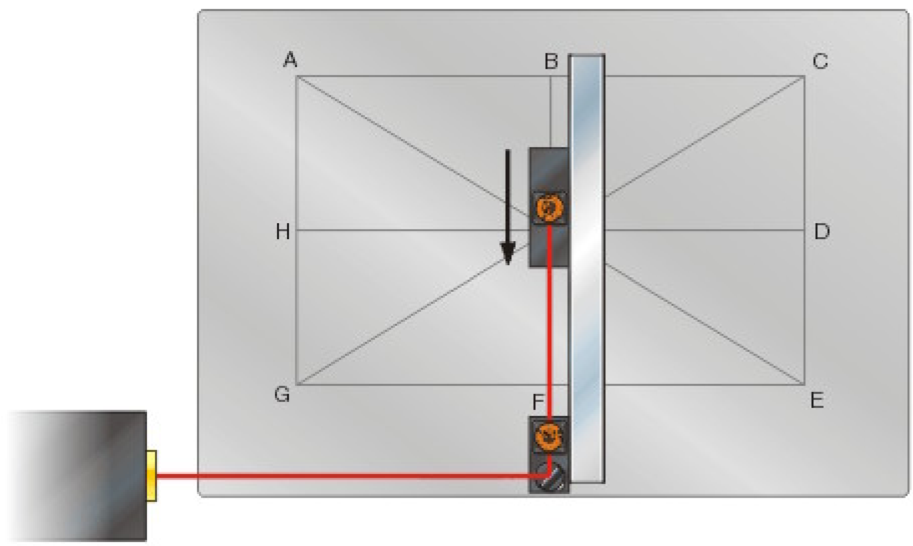

Figure 9 - Typical Moody measurement routine - centre line BF

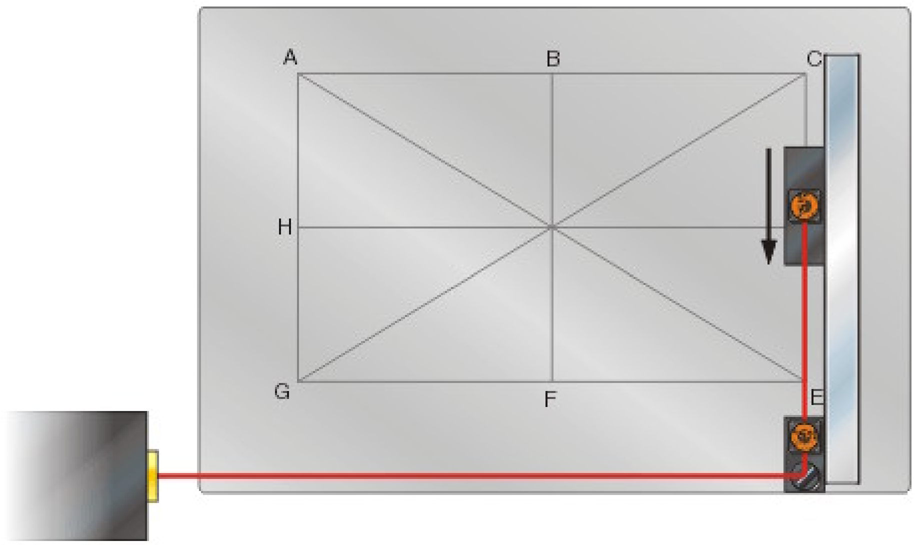

Figure 10 - Typical Moody measurement routine - perimeter line CE

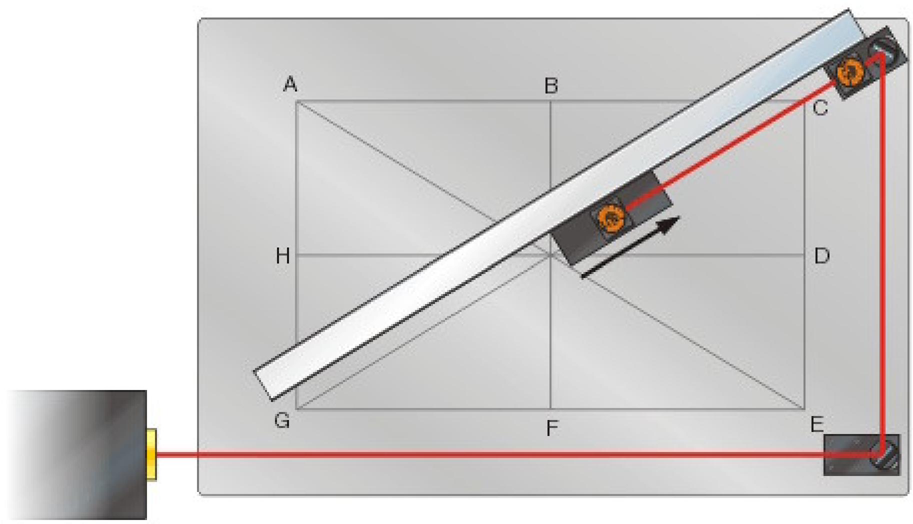

Figure 11 - Typical Moody measurement routine - diagonal GC

`Flatness measurement preparation and set-up - Issue 5.1`

Closure errors

Typical flatness contour plots are shown in Figures 1 and 2. The 'closure errors' reported are an indication of the validity of the data.

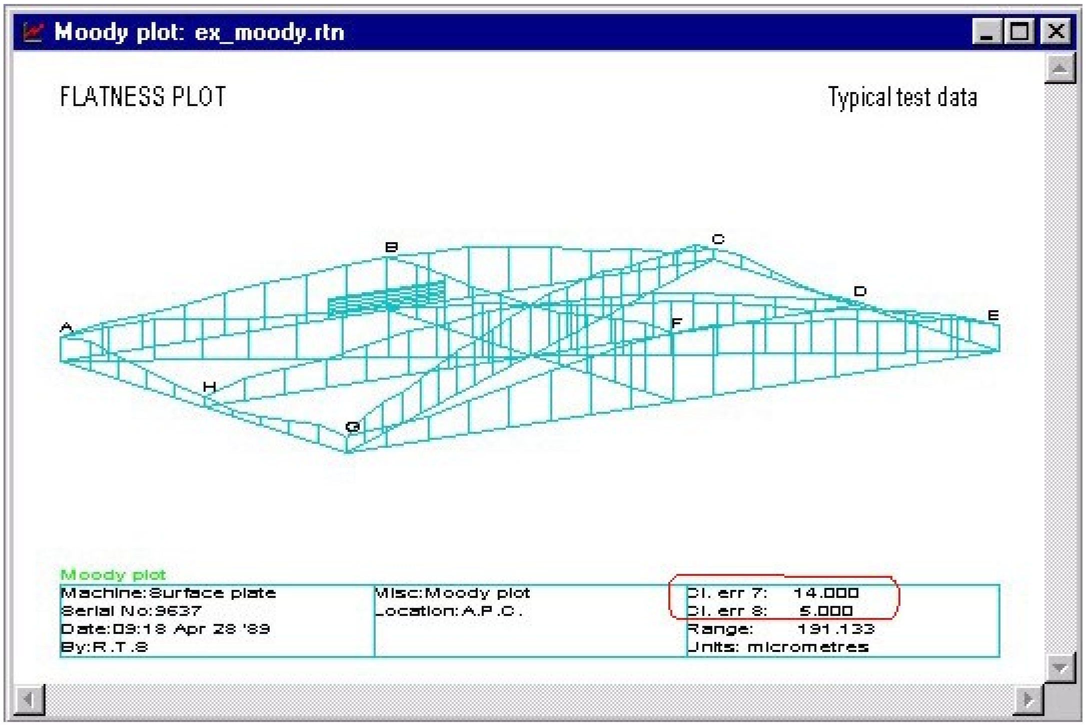

Figure 1 - Moody flatness contour plot

On the Moody plot, there are two closure errors, corresponding to the differences in readings between the intersection of the diagonals and lines FB and HD. These are known as closure errors 7 and 8 respectively.

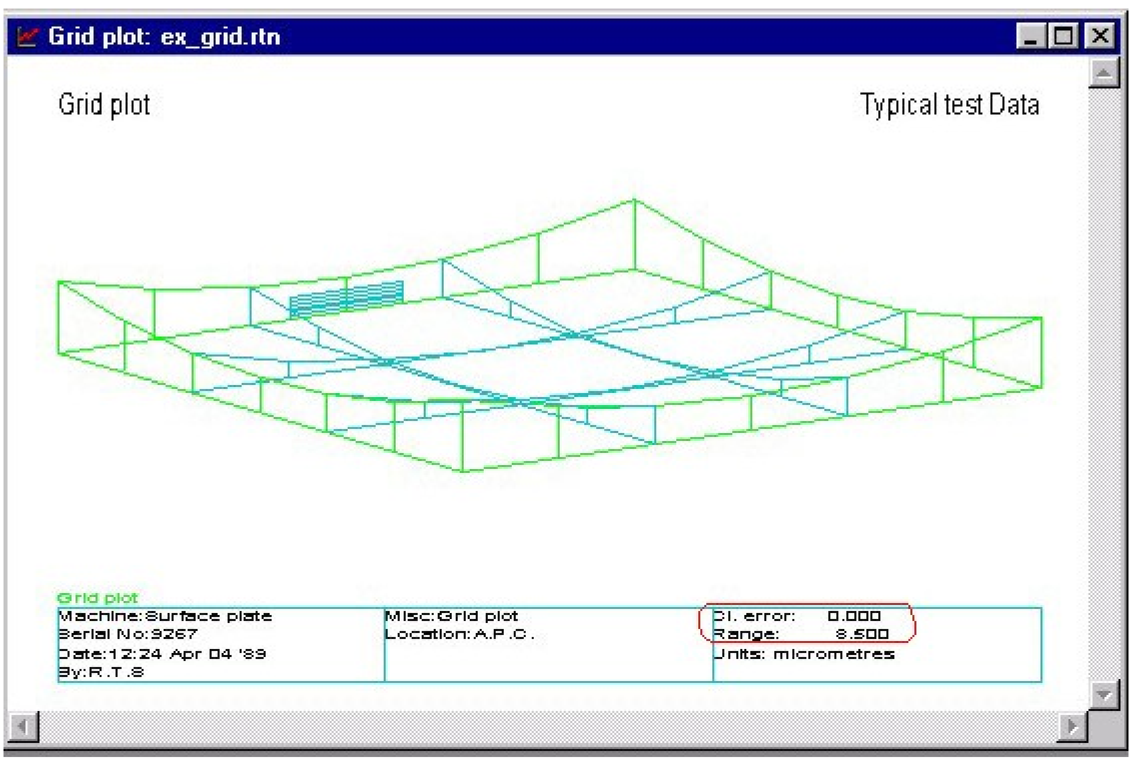

Figure 2 - Grid flatness contour plot

On the Grid plot, four reference points are defined, and the X and Y lines through these points are reference lines. There will be *n* closure errors, corresponding to the number of intersections between two non-reference lines. Only the maximum value is displayed.

With a Half-Grid plot there are no closure errors, since there are only two Y lines, both of which are reference lines.

The maximum value of the closure errors gives an indication of the validity of the calibration. If the worst closure error is less than 2.5 µm, the calibration can be considered to have been completed satisfactorily. If any closure error is greater than this value, the measurements and analysis may have to be repeated.

See factors affecting accuracy of flatness measurements.

Closure errors - Issue 5.1

Flatness beam alignment procedure

WARNINGS

1. TO AVOID RISK OF EYE DAMAGE, DO NOT STARE INTO THE LASER BEAM.
2. DO NOT LET THE BEAM PASS INTO YOUR EYES OR ANYONE ELSE'S, EITHER DIRECTLY OR BY REFLECTION FROM AN OPTICAL ELEMENT OR ANY OTHER REFLECTIVE SURFACE.

Align the optics so that measurement errors are minimised and acceptable beam strength is achieved over the entire length of travel of each measurement line.

Beam alignment measurement errors

To achieve an acceptable beam strength, the combination of lateral offset and maximum flatness deviation must not displace the angular reflector by more than ±1.5 mm (±0.06 in) in any direction from the nominal beam path. This should be achievable 'by eye'.

Use a straight edge to guide the flatness base along the measurement line. To avoid significant measurement errors, the straight edge should be straight to within 20 µm over the length of the longest measurement line.

Follow the instructions below to achieve acceptable beam alignment over the entire length of travel:

- If only one turning mirror is being used (i.e. the one to which the interferometer is fitted), follow the alignment procedure for one turning mirror.
- If two turning mirrors are being used, follow the alignment procedure defined under alignment with two turning mirrors.

Alignment with one turning mirror

This section describes the alignment procedure for measurement line BF as shown in Figure 1. However

this procedure can be modified for other measurement lines that require a single turning mirror.

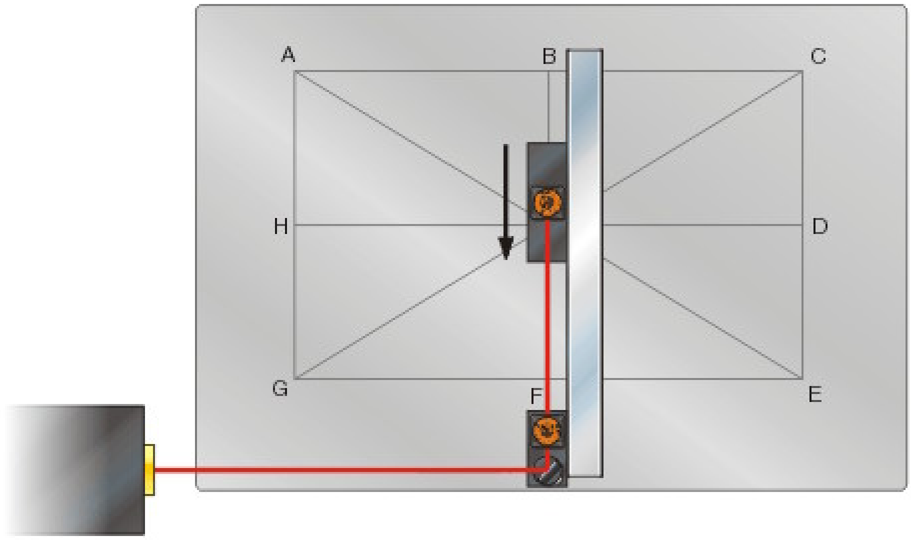

Figure 1

1. Place or clamp a straight edge along the marked line parallel to the line to be measured (see preparation and set-up) and place the angular reflector (mounted on its flatness base) at the near end of travel. Carefully position it so that the white line on the base is co-linear with the line to be measured.

2. Place the turning mirror/interferometer combination at least 8 mm (0.33 in) in front of the start point of the line to be measured, with the edge of the base abutted against the straight-edge as shown in Figure 2.

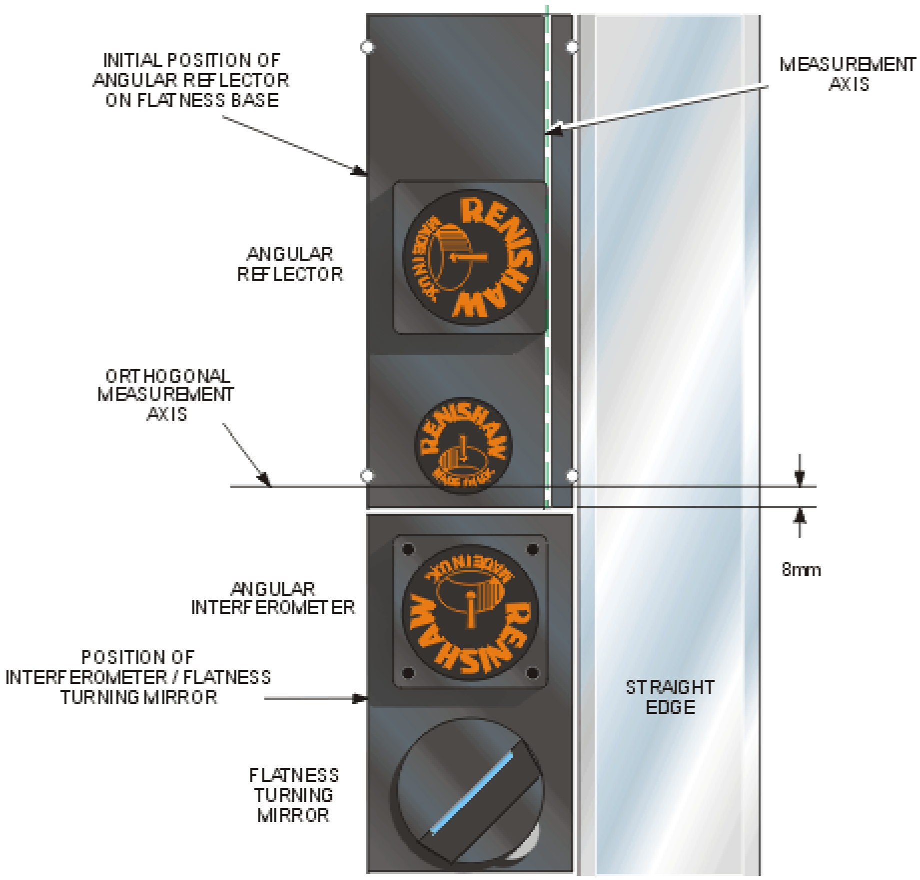

Figure 2 - Placement of interferometer

3. Rotate the shutter mechanism of the laser head so that the laser has a reduced output beam as shown in Figure 3.

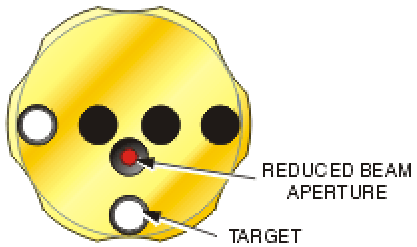

Figure 3 - ML10 shutter positions

4. Rotate the turning mirror so that it nominally faces the required direction.

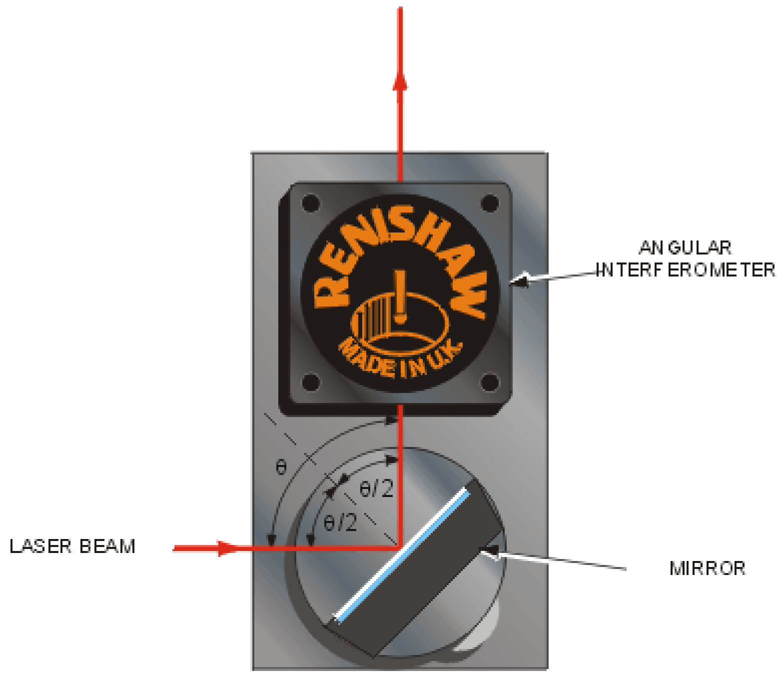

Figure 4 - Correct orientation of turning mirror

5. Adjust the laser/tripod so that the beam strikes the mirror in the correct position as shown in Figure 5. Use the white markings on the mirror for reference.

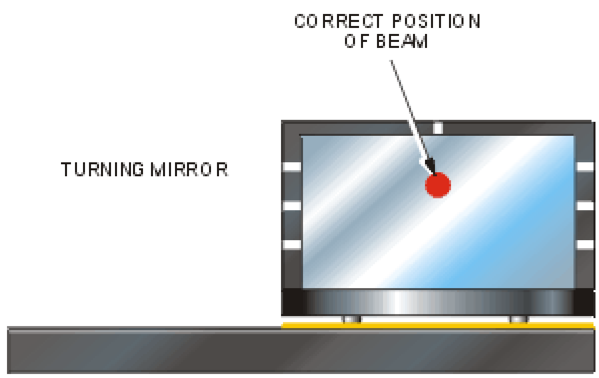

Figure 5 - Correct orientation

6. Place the angular reflector mounted on the flatness base at the furthermost point along the measurement line so that the twin reflectors are facing the turning mirror.

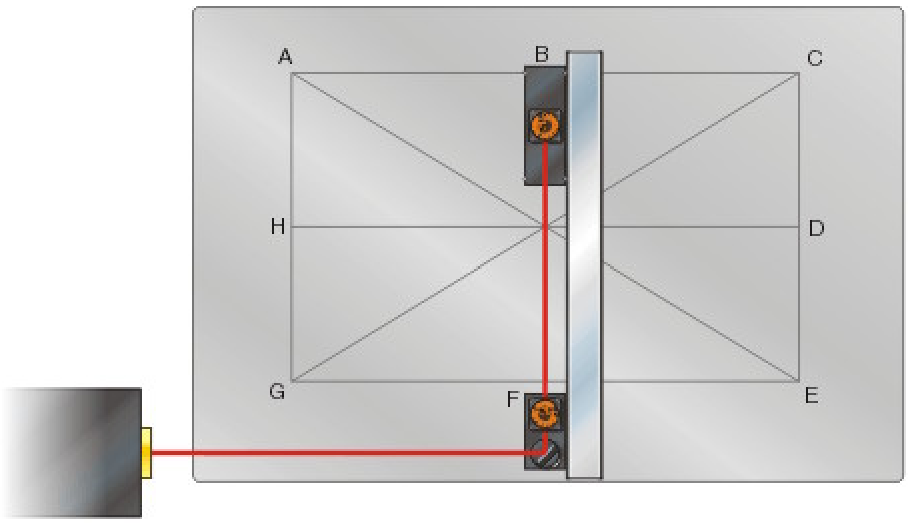

Figure 6

7. Rotate the turning mirror so that the beam passes through the angular interferometer and the resulting twin beams strike the angular reflector.

8. Pitch the turning mirror so that the twin beams strike the angular reflector at the correct height, if necessary using a target as shown in Figure 7.

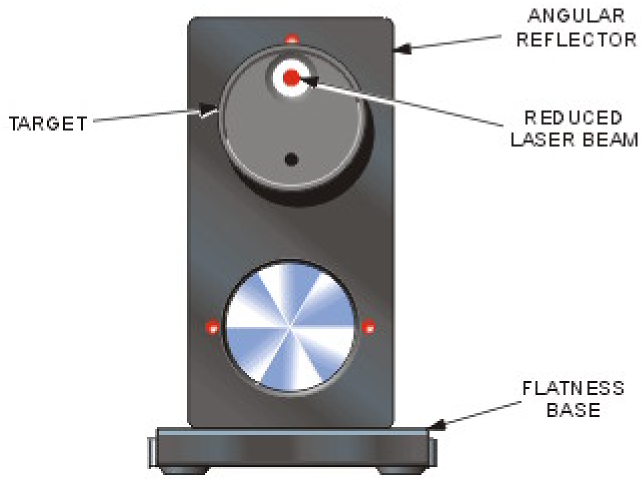

Figure 7

9. Remove the target and rotate the turning mirror so that the returning beam strikes the shutter on the front of the laser.

10. Pitch the turning mirror so that the return beam is at the same height as the target on the shutter.

11. Rotate the turning mirror again until the beam hits the shutter's target as shown in Figure 8.

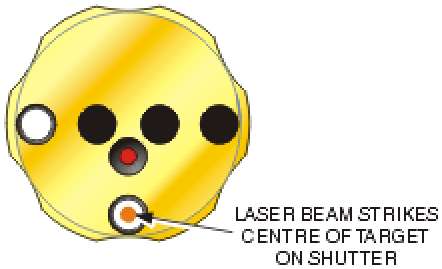

Figure 8

12. Move the angular reflector to the position of closest approach to the angular interferometer.

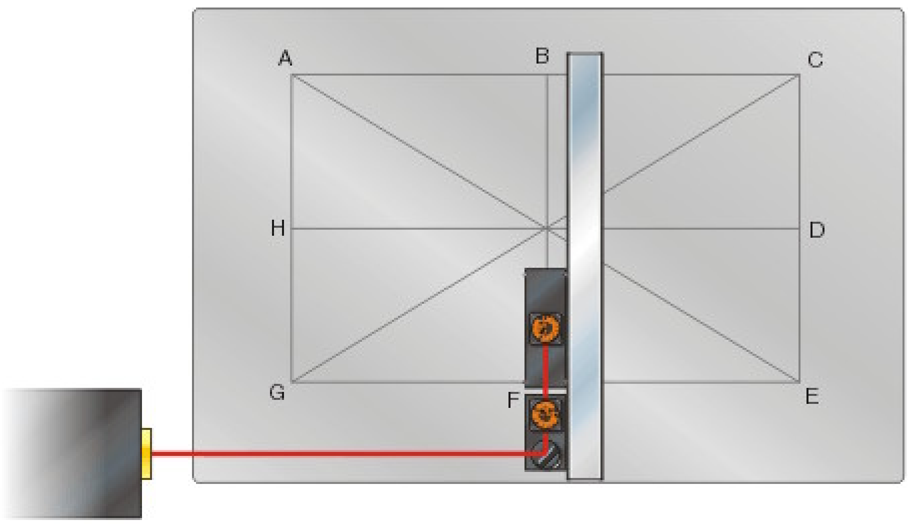

Figure 9

13. If necessary, adjust the horizontal and vertical translation of the laser to return the beam on to the target on the laser shutter.

14. Repeat steps 6 to 13 until the return beam strikes the shutter's target along the complete measurement line.

15. Rotate the laser's shutter so that the full diameter laser beam enters the laser detect aperture. Check that you achieve acceptable signal strength over the complete measurement line.

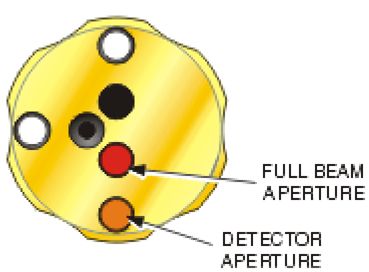

Figure 10

Alignment with two turning mirrors

This section describes the alignment procedure for measurement line EA as shown in Figure 1. However, this procedure can be modified for other measurement lines that require two turning mirrors.

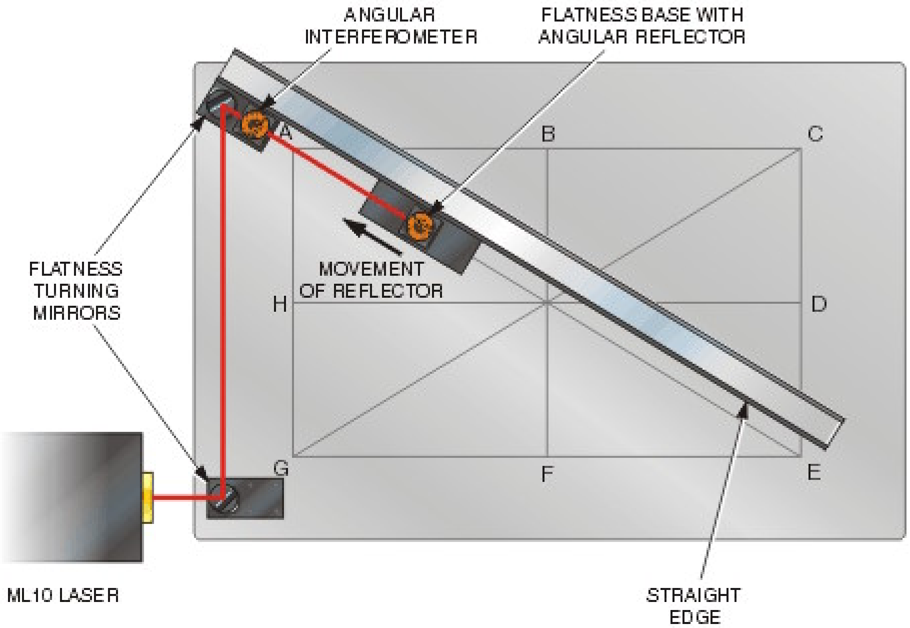

Figure 1

1. Place or clamp a straight edge along the marked line parallel to the line to be measured (see preparation and set-up) and place the angular reflector (mounted on its flatness base) at the near end of travel. Carefully position it so that the white line on the base is co-linear with the line to be measured.

2. Place the first turning mirror/interferometer combination at least 8 mm (0.33 in) in front of the start point of the line to be measured, with the edge of the base abutted against the straight edge as shown in Figure 2.

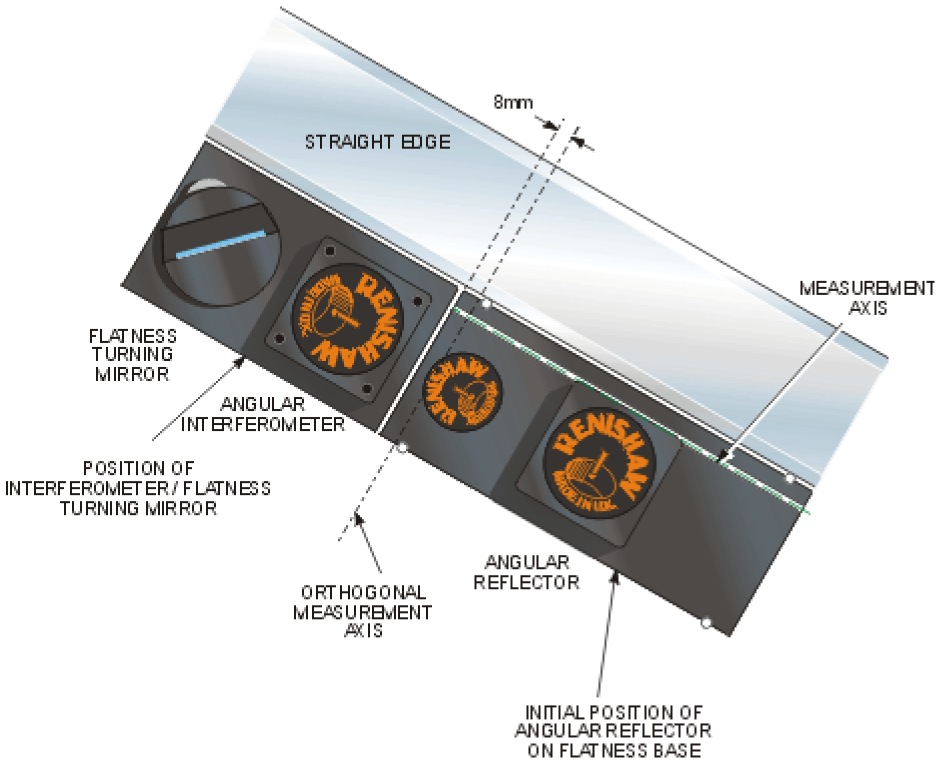

Figure 2 - Placement of interferometer

3. Rotate the shutter mechanism of the laser head so that the laser has a reduced output beam as shown in Figure 3.

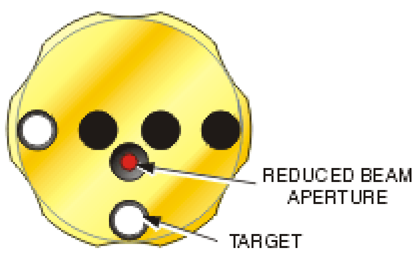

Figure 3 - ML10 shutter positions

4. Place the second turning mirror in front of the laser and rotate the second turning mirror so that it nominally faces the required direction as shown in Figure 4.

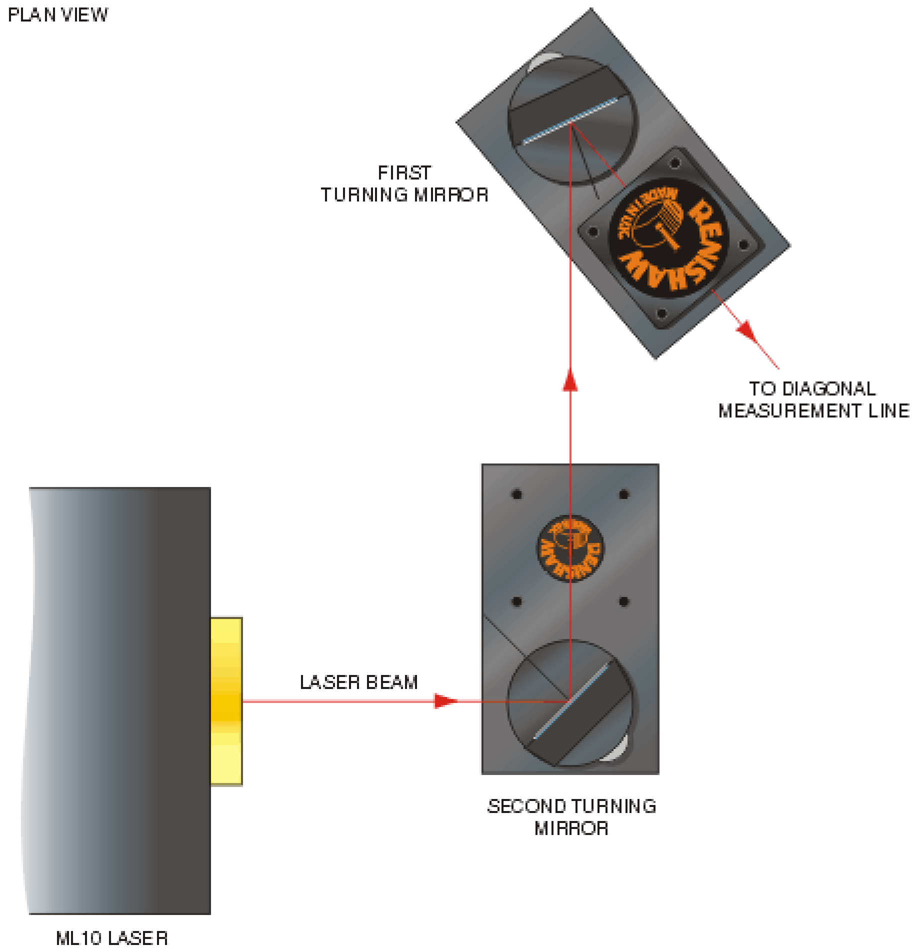

Figure 4 - Alignment of two mirrors

5. Adjust the laser/tripod so that the beam strikes the second turning mirror in the correct position.

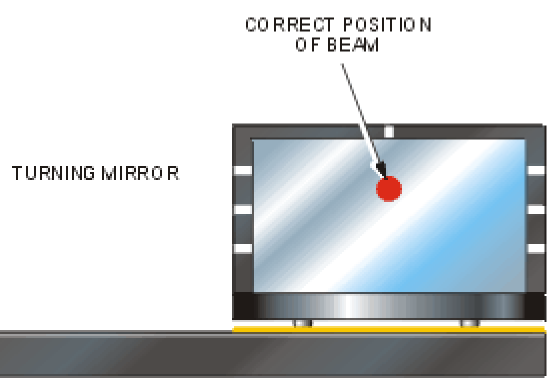

Figure 5

6. Rotate the first turning mirror so that it nominally faces its required direction.
7. Pitch and rotate the second turning mirror so that the beam strikes the first turning mirror in the correct position as shown in Figure 6.

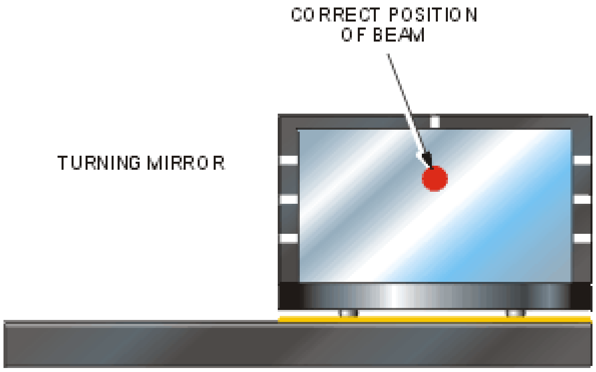

Figure 6

8. Place the angular reflector at the furthermost point along the measurement line, with the twin reflectors facing the first turning mirror.

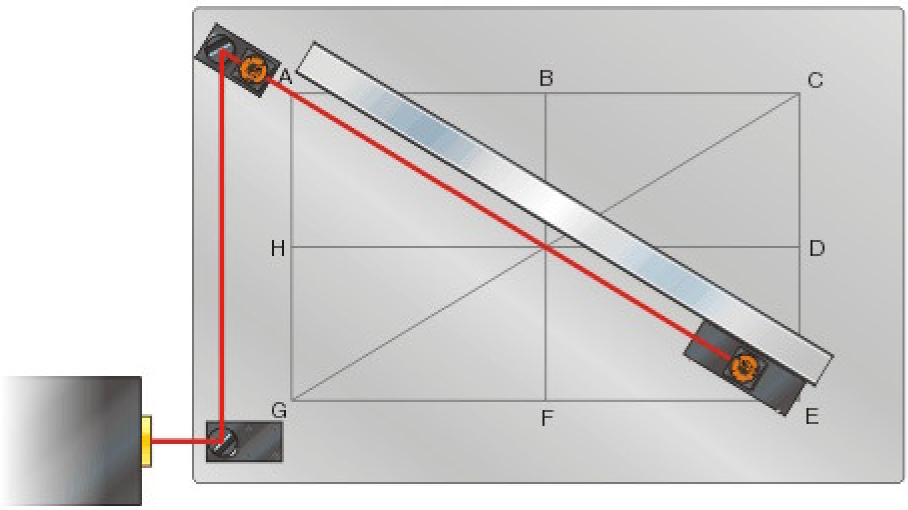

Figure 7

9. Rotate the first turning mirror so that the beam passes through the angular interferometer and the resulting twin beams strike the angular reflector.

10. Pitch the first turning mirror so that the beam strikes the angular reflector at the correct height, using a target if necessary.

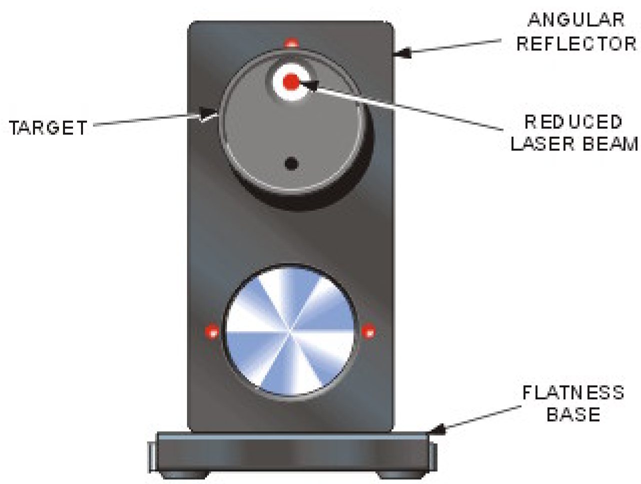

Figure 8

11. Remove the target and rotate the first turning mirror so that the returning beam strikes the shutter on the front of the laser.

12. Pitch the first turning mirror until the return beam is at the same height as the target on the shutter.

13. Rotate the first turning mirror again until the beam strikes the shutter's target as shown in Figure 9.

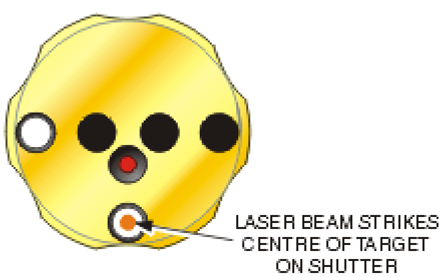

Figure 9

14. Move the angular reflector to the position of closest approach to the angular interferometer.

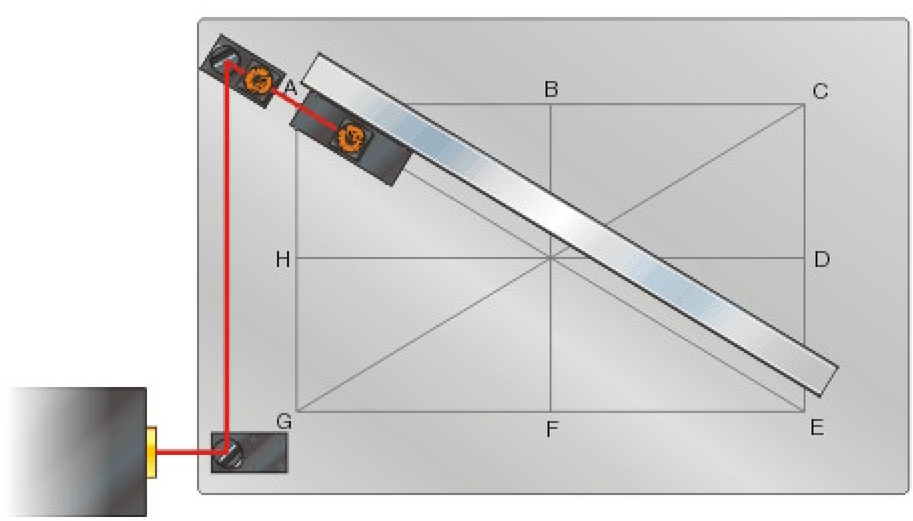

Figure 10

15. If necessary, horizontally and vertically translate the laser to return the beam on to the shutter's target.

16. Repeat steps 8 to 15 until the return beam strikes the shutter's target.

17. Rotate the laser's shutter so that the full diameter laser beam enters the laser detect aperture as shown in Figure 11. Check that you achieve acceptable signal strength over the complete measurement line.

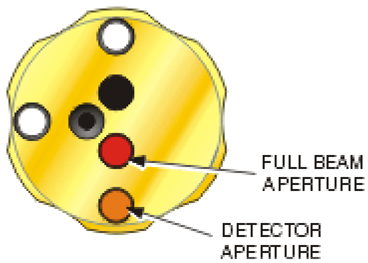

Figure 11

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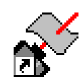
Flatness beam alignment procedure - Issue 5.1
```


Flatness data capture software

Running the flatness data capture software

If you have not already done so, run the flatness data capture software by selecting the  icon in the Renishaw Laser10 explorer window. The screen will show the flatness data capture software shown in Figure 1.

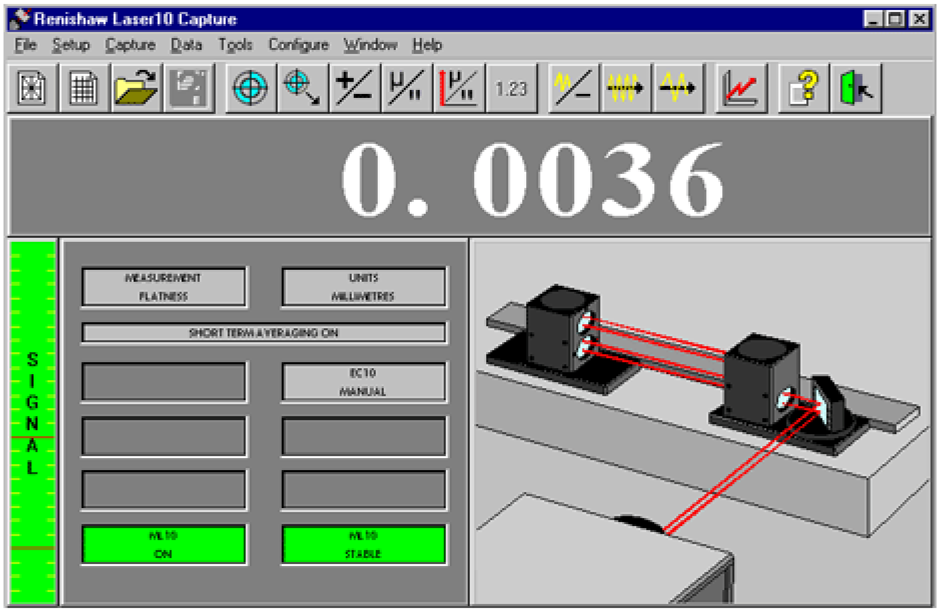


Figure 1 - Flatness data capture screen display

The digital display at the top of the screen does not appear until the method of test (Moody or Grid) and the required foot-spacing have been selected. The reading indicates the 'height' of the front foot of the flatness base with respect to the rear foot (see principles of operation).

Set up the data capture software. The set-up method depends whether you are using the Moody method or Grid method to calibrate the surface plate.

- Moody method set-up
- Grid method set-up

Moody plot data capture set-up

Select Set-up/Moody Set-up from the menu bar, or click on the button on the toolbar.

The foot-spacing dialog box will now be displayed, and the required foot-size can be selected.

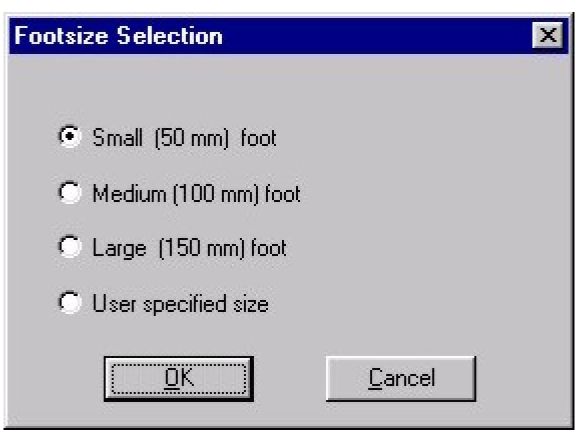


Figure 2 - Foot-spacing dialog box

Select from Small, Medium or Large as shown, or click the User specified size button, which allows you to enter the size of your choice.

The screen will now change to the Moody Set-up dialog box as shown in Figure 3. The selected foot-spacing is identified on the top line. To alter the selected foot-spacing, click the <C button and make a new selection.

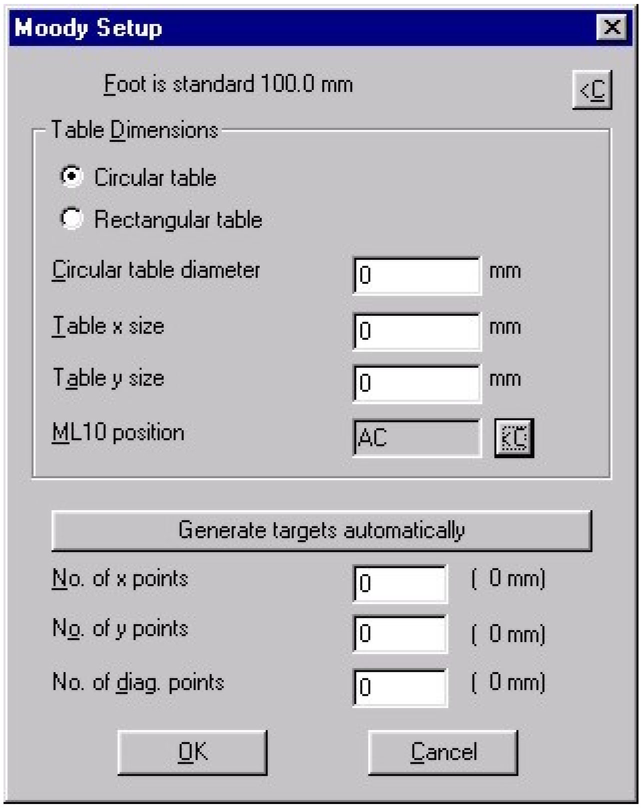


Figure 3 - Moody set-up dialog

The top section of the dialog box relates to the shape of the table and the maximum size of the Moody plot which is to be mapped (see preparation of surface plate for limitations).

When the choice of circular or rectangular table has been made, the 'effective' table dimensions can be entered. For a rectangular table, enter the lengths of the measurement axes in the Table x size and Table y size fields. For circular tables, enter the table diameter in the Circular table diameter field.

The location of the laser is defined by the ML10 position entry. To change the laser location, click on the button marked <C at the end of the line. A screen similar to the following is now displayed:

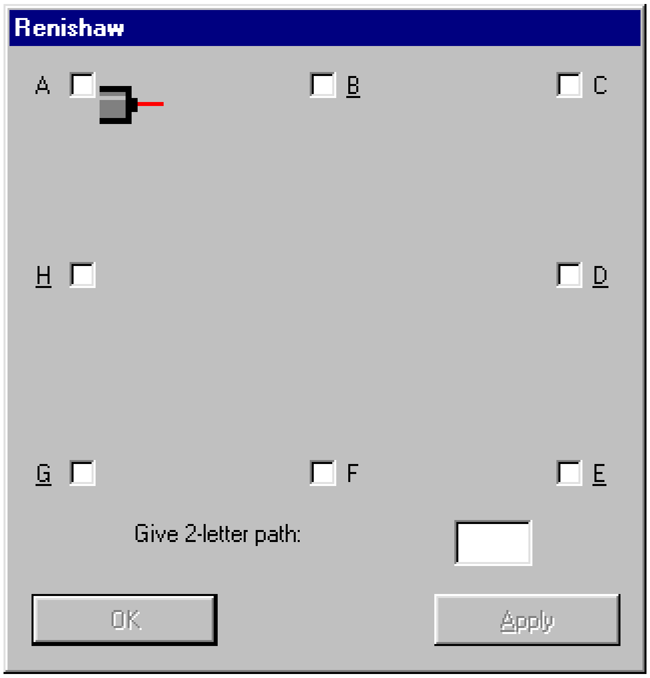


Figure 4 - Moody plot - laser location

The current position and alignment of the laser are shown. To change the position, either enter any of the following two-letter path codes in the box, for example AC, AG, CA, GE, GA, CE, EC, EG, AE, BF, CG, DH, EA, FB, GC and HD, or tick the appropriate boxes. Click the Apply button and the laser will then be shown in the new position, for example:

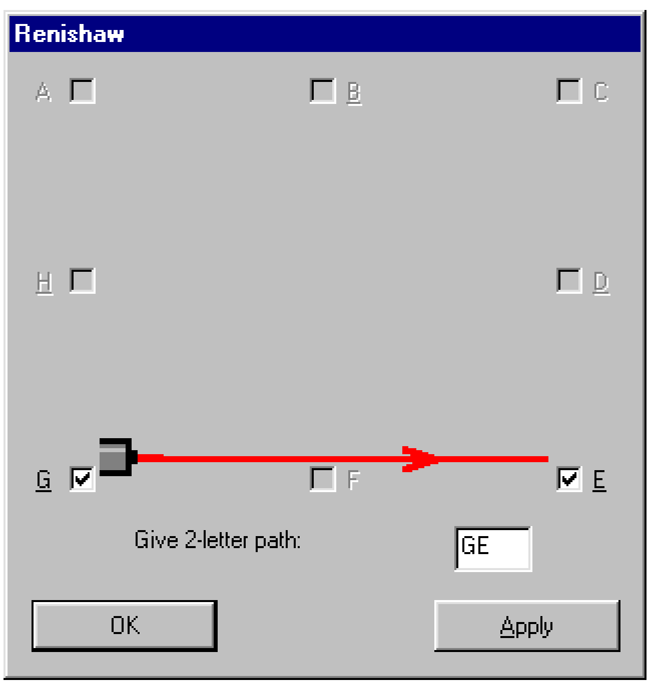


Figure 5 - New laser position

When you are satisfied with the new laser position, click OK and the screen will return to the Moody set-up dialog, amended to show the new position for the laser.

The Generate targets automatically button provides the facility to identify a series of options for the number of targets which can be accommodated on each of the measurement lines.

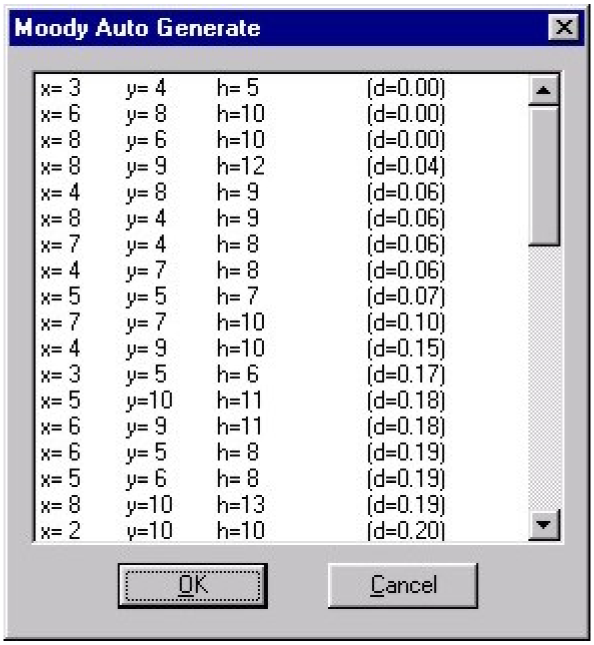


Figure 6 - Moody plot target options

Each line in the display provides an option for the numbers of targets to be defined for each X and Y measurement line, and for each diagonal 'h'. It also defines the value 'd', where 'd' is the fractional part of the solution to:

$$\frac{\text{length of diagonal}}{\text{foot-spacing}}$$

The lower the value of 'd', the better the prospects of achieving acceptable closure errors. As a rule of thumb, values of 'd' lower than 0.05 should yield acceptable closure errors.

Highlight the most appropriate line and click OK. The screen will then return to the Moody set-up dialog with the chosen numbers of targets for each measurement line displayed in the relevant box. The length of each measurement line, as defined by the specified foot-size and selected target number option, will also be displayed in brackets.

If the 'effective' table dimensions defined by the lengths of the measurement lines are not acceptable, an alternative selection can be made from the automatic target generation facility. Additionally, the number of targets specified for any measurement lines (i.e. X, Y, or diagonal) may be manually edited by over-typing the existing value. It should be noted however that if the manually entered/edited values lead to the measurement lines not being an integral number of foot-spaces, then high closure errors may result and the data taken may not be valid.

Once the correct information has been entered, click OK to proceed to the data title dialog box, where you can enter details of measurement. When these details have been entered, click OK to proceed.

Before capturing data for a measurement line, you will need to set up and align the laser and measurement optics.

Selecting Moody measurement lines

When all the Moody set-up data has been entered, the screen will change to the display shown in Figure 7 below:

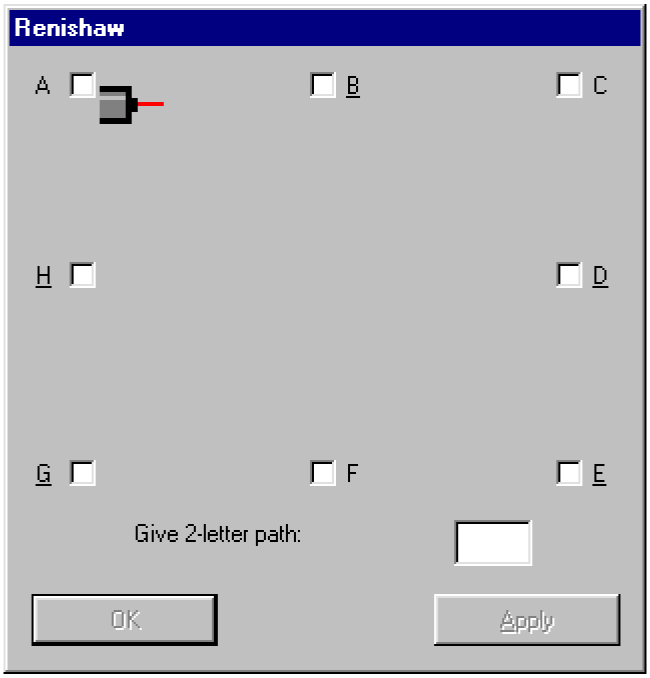


Figure 7 - Moody plot line selection (i)

You now need to select the measurement line to be measured. Do this by either giving the 2-letter path or by clicking on the appropriate letters on the screen. Note that the order in which the two letters are entered defines the direction in which the moving optic will travel, for example BF would be from B to F, and FB from F to B.

The screen will change to the display shown below in Figure 8, with the arrowed line corresponding to the measurement line direction selected.

Note: The position of the laser is shown on the display.

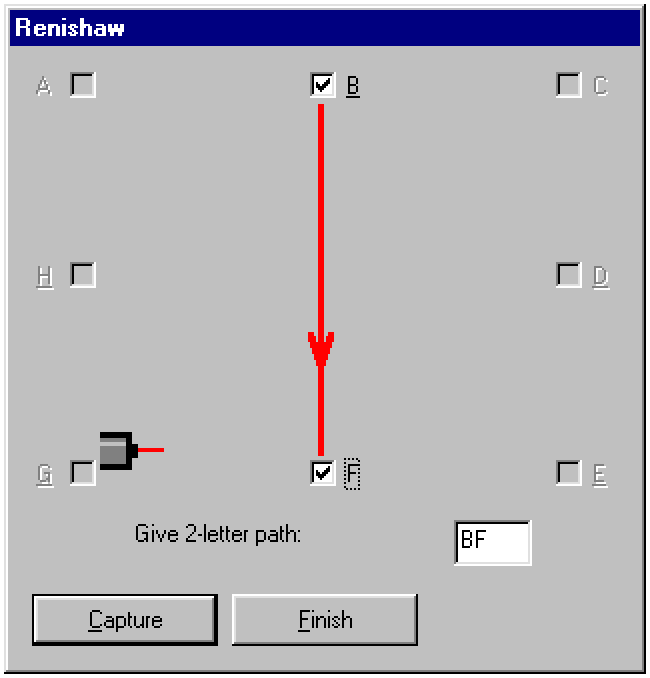


Figure 8 - Moody plot line selection (ii)

Ensure that the arrow does indicate the required line and direction for the first set of measurements and click OK.

The screen will change to the display shown in Figure 9 below, awaiting entry of measurement data.

Flatness data capture

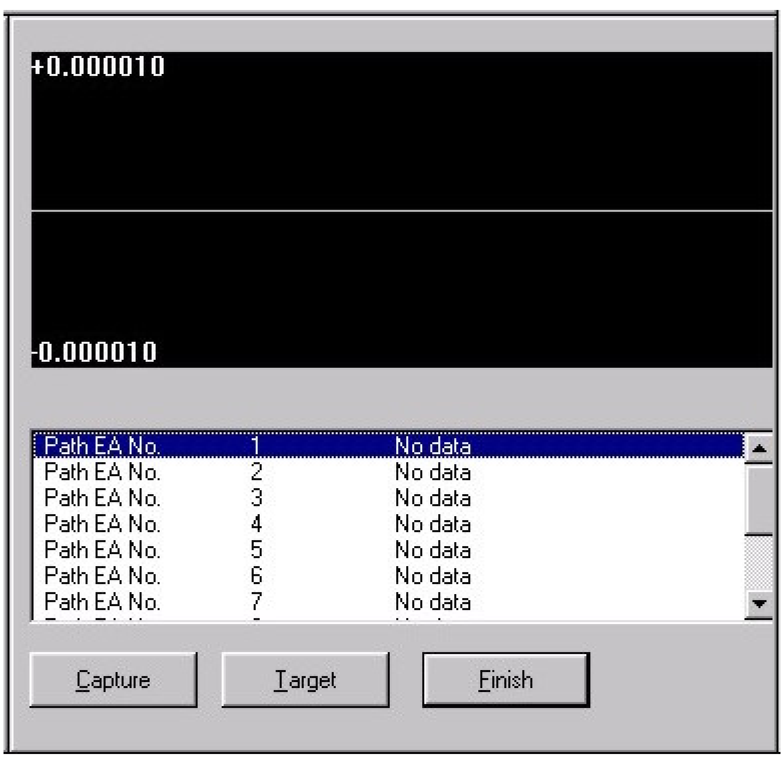


Figure 9 - Moody plot line selection (iii)

Grid plot data capture set-up

Select Set-up/Grid Set-up from the menu bar, or click on the button on the toolbar.

The foot-spacing dialog box will now be displayed, and the required foot-size can be selected.

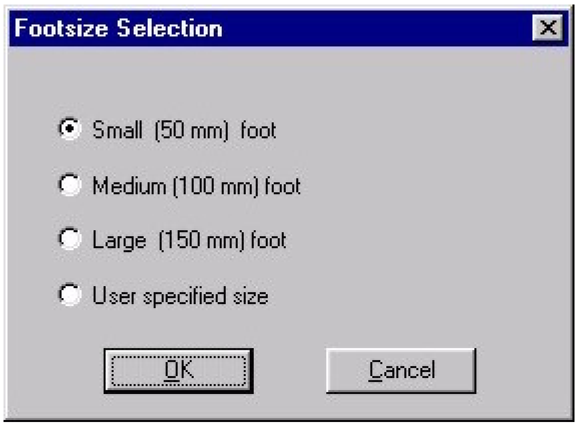


Figure 10 - Foot-spacing dialog box

Select from Small, Medium or Large as shown, or click the User specified size button, which allows you to enter the size of your choice.

The screen will now change to the Grid Set-up dialog box as shown in Figure 11. The selected foot-spacing is identified on the top line. To alter the selected foot-spacing, click the <C button and make a new selection.

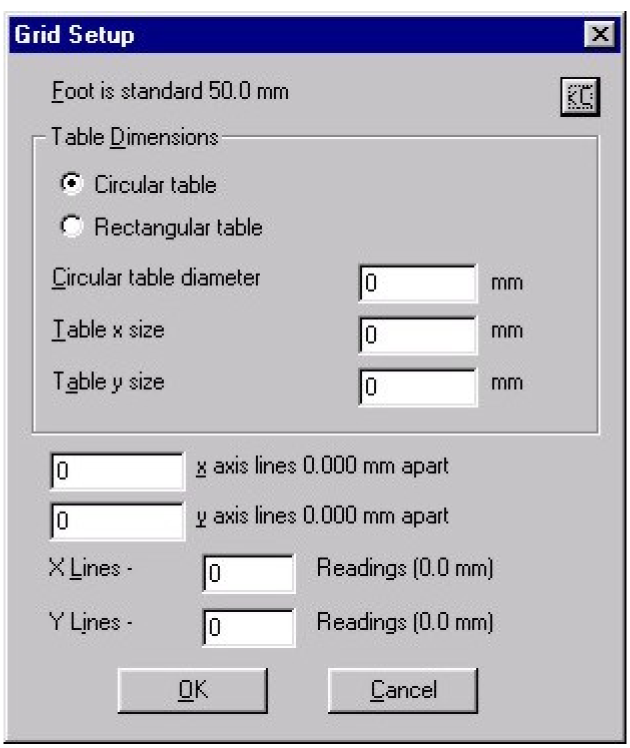


Figure 11 - Grid set-up dialog

Note: The separation between X axis measurement lines need not be the same as that between Y axis measurement lines and neither X or Y axis need be a multiple of the foot-spacing used. The overall length of each measurement line will be determined by the number of targets selected and the foot-spacing used.

Enter the required numbers of lines or the number of readings in the appropriate boxes. The system will now calculate and display the line separations and overall lengths.

If any of the dimensions defined prove to be unacceptable, the appropriate entry can be edited.

When the Moody or Grid set-up is complete, click OK to proceed to the data titles dialog box, where you can enter measurement details (for more information, see machine title information). When measurement details have been entered, select OK to proceed.

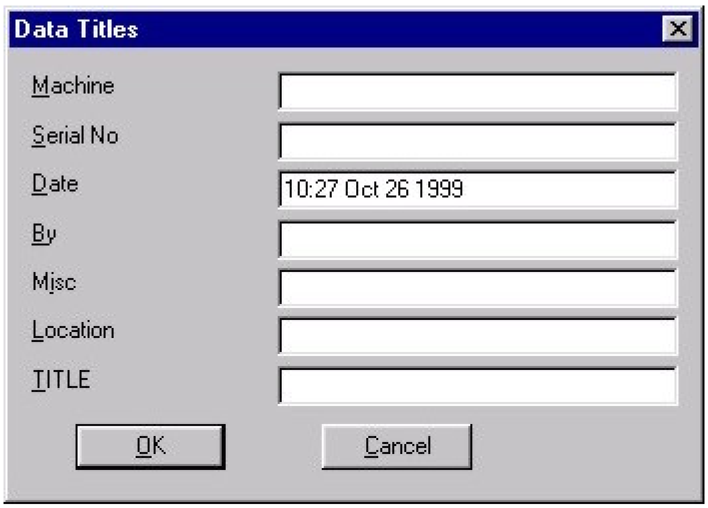


Figure 12 - Data titles dialog box

Establishing the grid plot reference plane

To successfully perform a Grid plot flatness measurement using a laser interferometer system, it is necessary to first define the height (from a nominal plane) of four reference points within the grid, using an alternative technique (e.g. a Moody plot).

This is done by selecting Set-up/Reference Plane from the menu bar. The following dialog box is displayed:

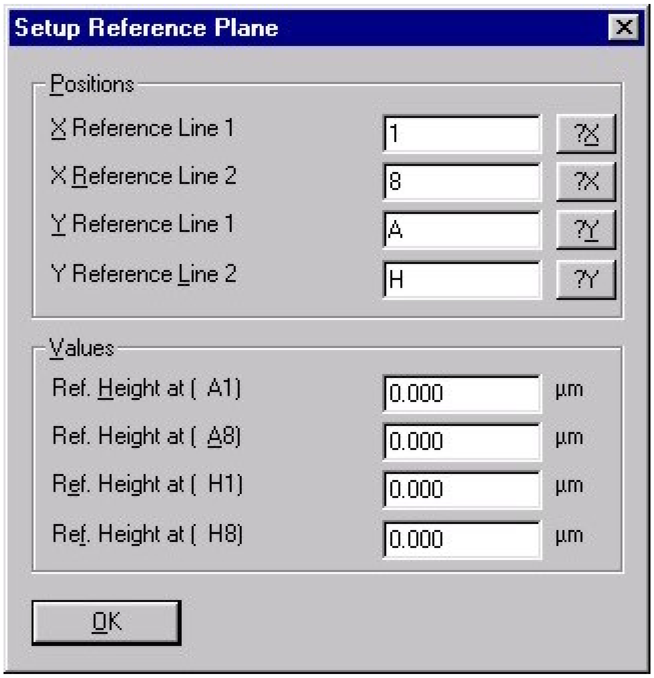


Figure 13 - Grid plot - reference plane entry dialog

Enter the start and end points of the two X reference lines and two Y reference lines, or pick them from the list by clicking on the ?X or ?Y button to the right of the box.

The four reference points are now defined as the intersection points of these four lines and the reference height of each point can be entered.

Selecting grid measurement lines

When all table, target, machine and measurement data has been entered to your satisfaction, the screen will change to the display shown below:

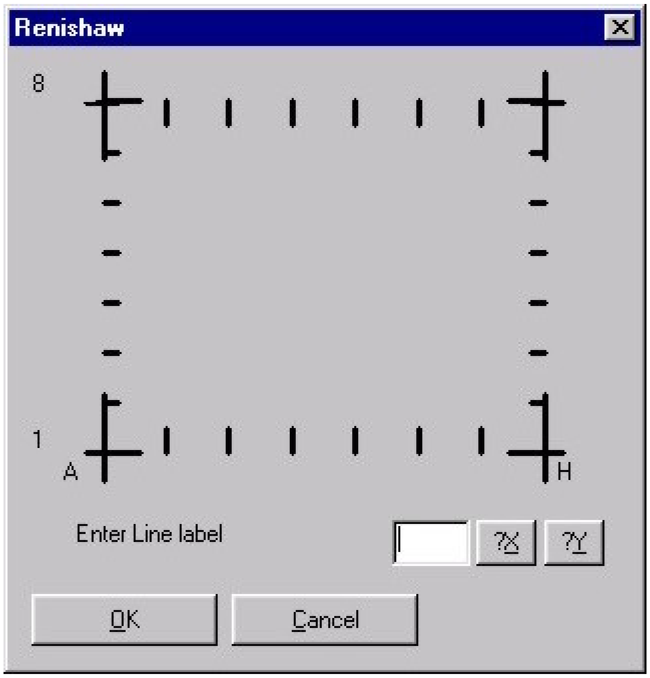


Figure 14 - Grid plot line selection (i)

The first measurement line to be addressed can be selected by entering the alpha-numeric followed by OK. (The X axis measurement lines are identified by numbers; the Y axis measurement lines are identified by letters, the 27th line being AA, etc.) Alternatively, click on the ?X and ?Y buttons and select the measurement line from the list displayed.

The screen will change to a display similar to that shown below, with the selected path (e.g. A+) specified, awaiting capture of measurement data.

Flatness data capture

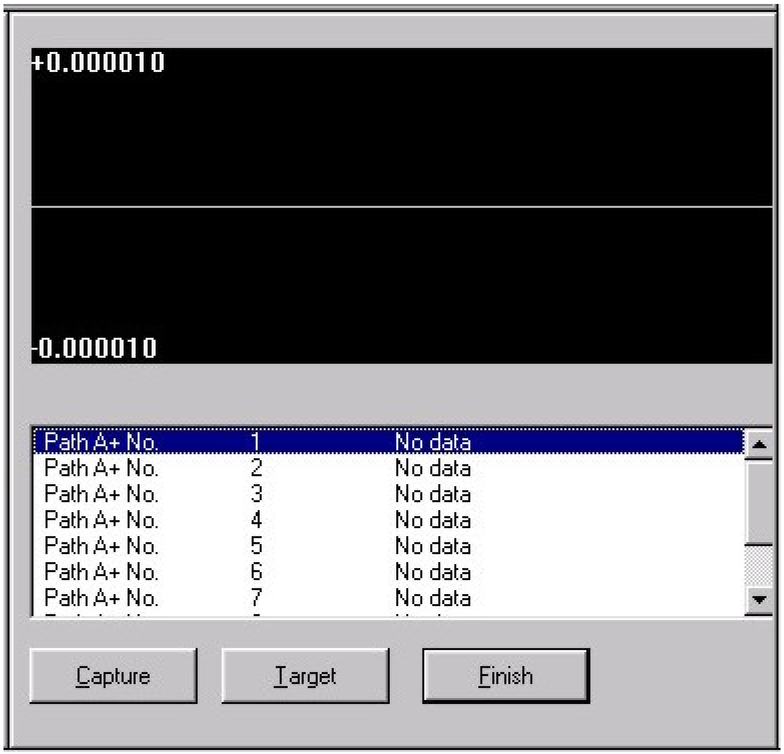


Figure 15 - Grid plot line selection (ii)

Flatness data capture

When beam alignment has been achieved (see Beam alignment procedure) and the target positions have been set Setting up targets (Moody plot) and Setting up targets (Grid plot), place the moving optic in its initial position.

To confirm that the correct sign convention is followed, lift the front foot of the moving optic and observe the change in the interferometer reading. If necessary, change the sign of the reading by pressing [Ctrl]+[-].

Datum the laser interferometer system by pressing [Ctrl]+[D], then record a reading at the datum point by pressing [Alt] [C] buttons or by clicking on the Capture button.

Move the flatness base along the measurement line by a distance equivalent to one foot-size, and record a reading by pressing [Alt] [C]. The Y axis of the graph display (as shown in Figure 16) will auto-range in accordance with the error value recorded; the error value itself will be displayed alongside the target below the graph.

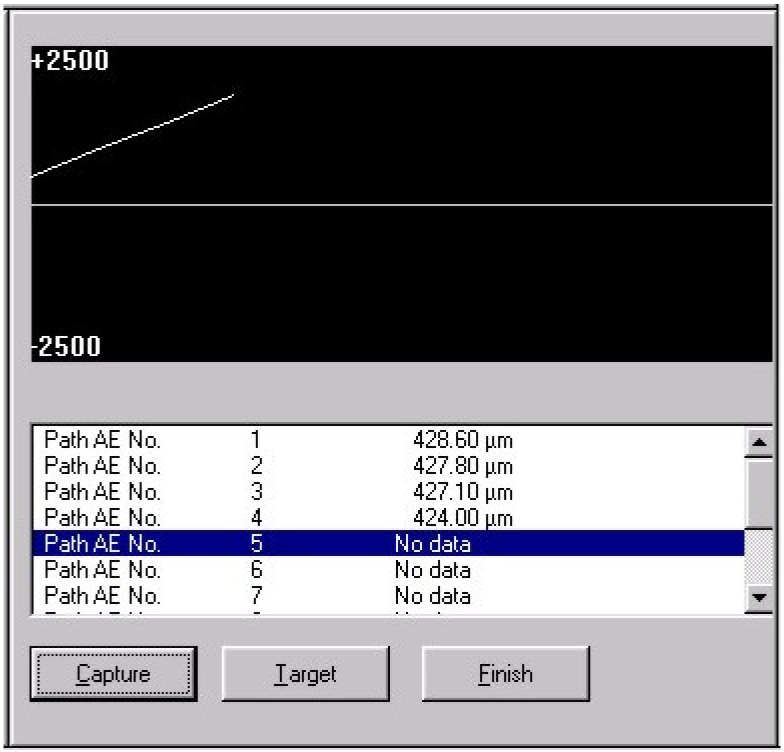


Figure 16 - Data capture

Move the flatness base along the measurement line by a distance equal to one foot-size, and record a third reading by pressing [Alt] [C].

Continue to record readings at foot-size intervals until readings have been taken at all target positions along the first measurement line.

The Data Capture Complete dialog is displayed. Click OK and then click on the Finish button.

Next capture data for the next measurement line.

Set up and align the measurement optics

Note: The measurement line that has already been logged will remain on the screen.

Continue the above process until measurement readings have been recorded on each line.

Then save the captured data before performing flatness analysis.

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Flatness data capture software - Issue 5.1
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Sign convention

A suitable sign convention must be defined before data capture and analysis can take place. Renishaw

recommend the use of the following convention, which is independent of the position of the interferometer as shown in Figure 1.

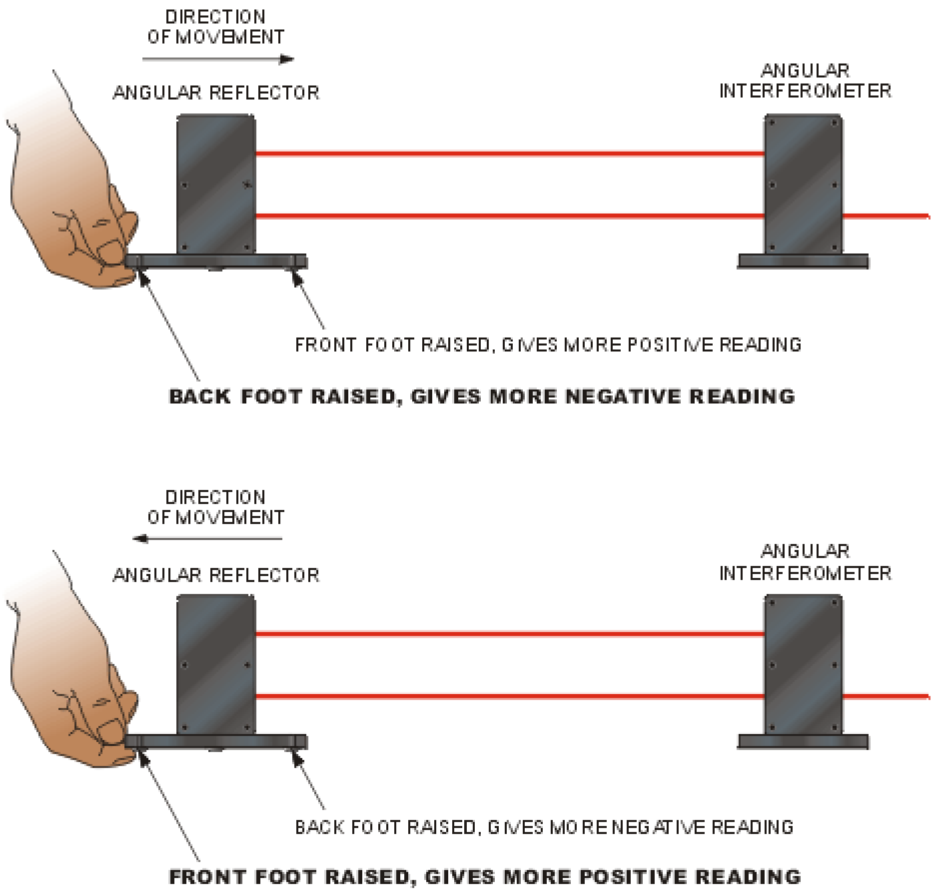


Figure 1 - Sign convention

- Positive readings - the front foot of the flatness base is higher than the back foot
- Negative readings - the back foot of the flatness base is higher than the front foot

Note: The terms 'front' and 'back' relate to the direction of movement of the flatness base, so the same data taken along the same axis, but in opposite directions, will have opposite polarity or sign (as shown in Figure 1).

`Sign convention - Issue 5.1`

Flatness analysis

The Laser10 analysis software includes facilities for plotting the data to either Moody or Grid format.

Analysis software

The analysis software can be accessed by selecting Data/Analyse from the menu bar or by clicking on the  button on the toolbar of the flatness data capture software.

Now select the Analysis option from the menu bar and the following options are available:

- Moody or Grid plot
- Print numeric Moody or Grid data

Whether the Moody or Grid options are available depends on the data in the file loaded. In the following example, Moody has been selected.

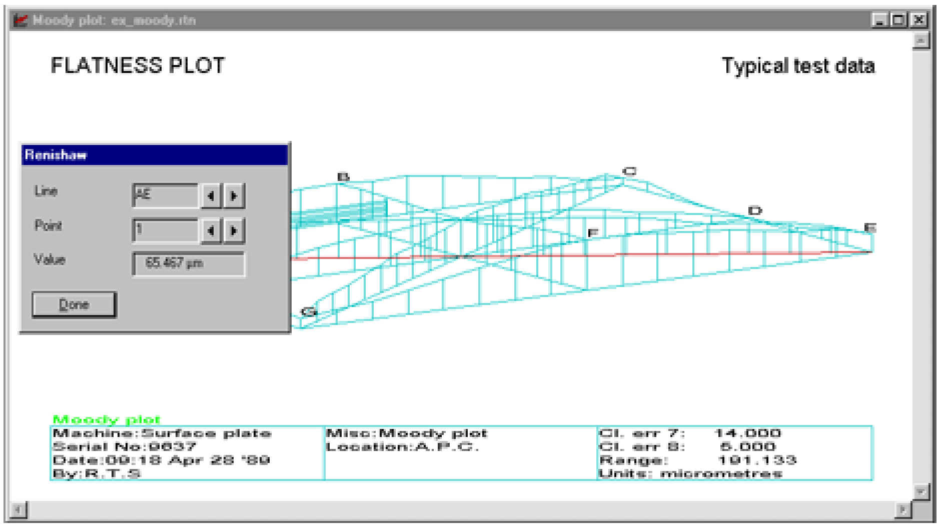


Figure 1 - Moody flatness contour plot

The control panel overlaid on top of the plot allows you to select the **line** and **point** that you want to analyse. Use the arrow keys to select the position that you want to analyse. The flatness error in micrometres is shown for the selected line and point. When you click on the Done key, the control panel is hidden.

Both Moody and Grid presentations include a characteristic statement of 'flatness range' in the box below the three-dimensional projection of the surface. The 'range' defines flatness of the measured surface as the separation of the planes which just enclose the measured surface as discussed in standard methods of assessing flatness.

The closure errors are also defined.

If you had selected **Grid**, the display would be as follows:

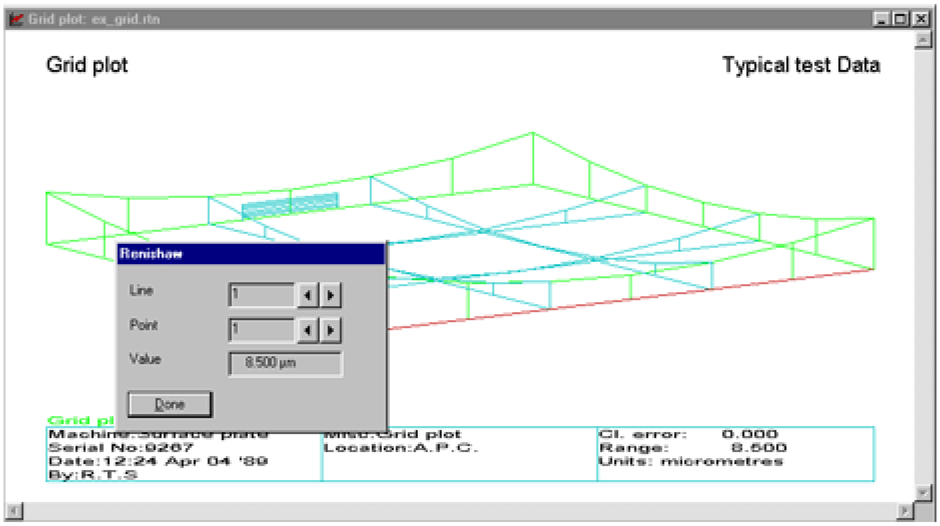
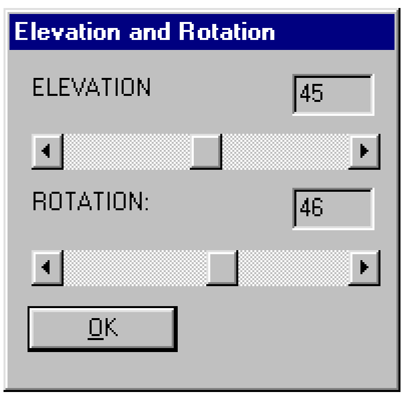


Figure 2 - Grid flatness contour plot

Plot options

The Plot/Elevation and Rotation option on the menu bar allows you to alter the projection of the plot. When you select this you will see the following:



You can now change the elevation and rotation by dragging the pointers. The effect can be seen by comparing Figure 3 (where the elevation and rotation are 45º and 75º respectively) with Figure 1 (where they are both 35º).

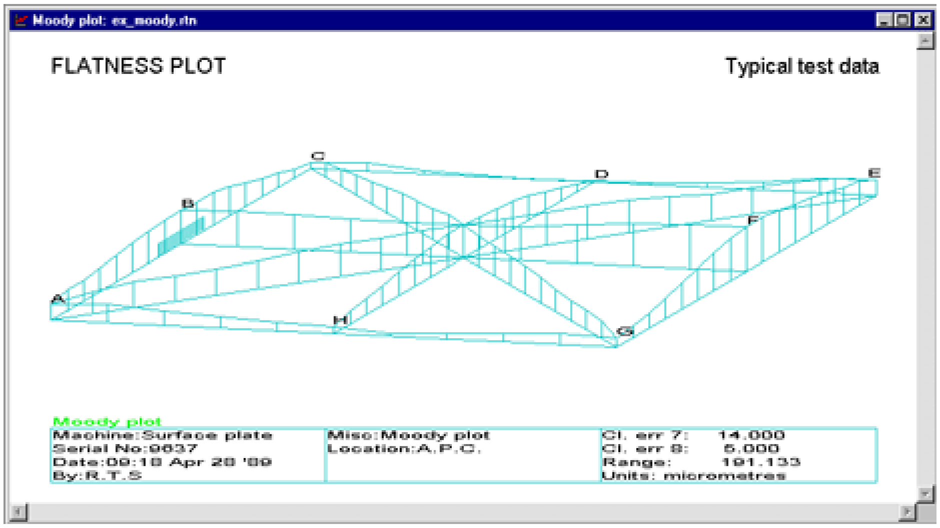


Figure 3 - Moody plot - alternative projection

The Plot/Units option on the menu bar allows you to alter the units being used. When you select this, you will see the following:

Use the mouse to select the units you want to use then click OK.

Flatness analysis - Issue 5.1

Factors affecting accuracy of flatness measurements

The following factors can affect the accuracy of measurement:

- Beam alignment error
- Angular optics error
- Differential expansion of flatness base feet
- Repeatability of measurements

Beam alignment error

As discussed in Beam alignment procedure, the error in alignment between the laser beam and the measurement line will affect the accuracy of measurement. The maximum alignment errors allowed to achieve the measurement accuracies given in the Specifications section are shown below:

Flatness base	Maximum alignment error
50 mm 100 mm 150 mm	81 arc min 54 arc min 27 arc min

These alignments should be achievable 'by eye'.

Note: An alignment error of 1.5 arc min is equivalent to a 0.5 mm error over 1 m.

Differential expansion of flatness base feet

Differential expansion of the front and back feet of the flatness base will cause an error. As with the angular reflector housing, the flatness base should be handled as little as possible during a measurement and should be kept away from heated or cooled surfaces or air masses so that its temperature remains stable.

Repeatability of measurements

Any accumulation of dirt particles or granite 'dust' under the feet of the flatness base can introduce a measurement error. Measurement errors are often signified by a large closure error. To reduce measurement errors to a minimum, the reflector should be moved to the centre of the line and the laser system zeroed. The reflector should then be moved from end to end along the measurement line several times, while the readings from the laser read-out are observed. These readings should be repeatable to within 0.5 µm (0.2 thou) on a clean and good quality surface.

`Factors affecting accuracy of flatness measurements - Issue 5.1`