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Plane mirrors for laser applications

Overview

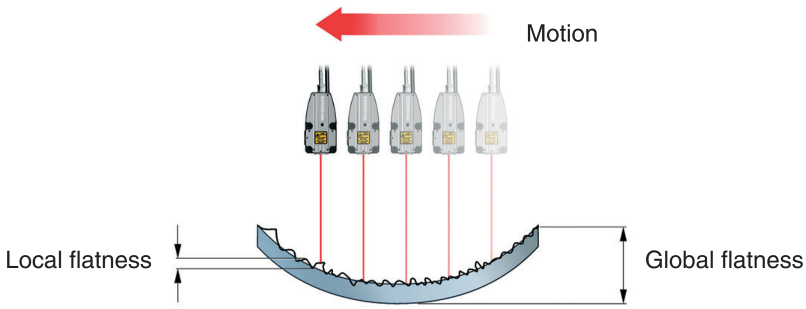
Mirror selection and integration should be carried out carefully to avoid degrading the metrological advantages of an interferometer system. In the case of an X-Y stage system, mirrors can contribute to system errors through:

- **Surface non-uniformity (flatness)**, which can be minimised by using an optically flat mirror and correct mounting techniques
- **Thermal expansion**, which can be reduced by using the correct substrate materials and mounting techniques
- **Mirror misalignment**, which can be avoided through careful installation

Mirror flatness

In multi-axis applications, such as an X-Y stage, the interferometer laser beam will traverse the length of the mirror as the stage travels along the cross axis. An uneven surface results in a path length change between the mirror and the interferometer which cannot be distinguished from actual motion. Mirror flatness is usually specified as local and global.

Note: in the image below mirror non-flatness has been exaggerated for clarity, and the detector head is shown to move instead of the stage



Flatness is usually specified as a 'peak to valley' figure quoted as a fraction of a wavelength over a particular length. For example:

- Local flatness specification: λ/10 over an area of 12 mm x 7 mm
- Global flatness specification: ~ λ/4

Local flatness*	Maximum error (nm)
λ/4	158
λ/8	79
λ/10	63
λ/12	53
λ/20	32

* λ = 633 nm

Application note

Local flatness

Distortions of the mirror can degrade the fringe contrast in the interferometer and cause measurement errors. Local flatness measurement errors can be reduced by purchasing mirrors with a very high flatness specification over the entire optical aperture. This is suitable when using small mirrors but notoriously expensive when longer mirrors are required.

Global flatness

Global flatness specifications consider structural distortion of a mirror that can cause measurement errors and beam misalignment. Global distortion is very much dependent on the method of mounting used. Most motion controllers are capable of generating a flatness correction table, which means it is possible to compensate for any residual distortion after mounting to correct for this error.

Thermal expansion

Mirror substrate material can contribute to measurement error through thermal expansion (although it will usually be negligible when compared to the expansion of the rest of the system). In order to minimise this error, a material with a low coefficient of thermal expansion (CTE) should be used for the mirror substrate.

	CTE (ppm/ºC)	Maximum error* (µm)
Low thermal expansion glass	0.1	0.003
Fused silica	0.5	0.013
Typical glass	8	0.24

* 25 mm thick substrate and 1 ºC temperature change

Thermal expansion effects / distortions can be reduced by using an appropriate mirror mount, such as those supplied by Renishaw. See data sheet Plane mirrors and mirror mounts (L-9904-2446) for more information.

Cosmetic surface quality

Poor cosmetic surface quality can reduce signal intensity and possibly cause beam mis-alignment and measurement errors.

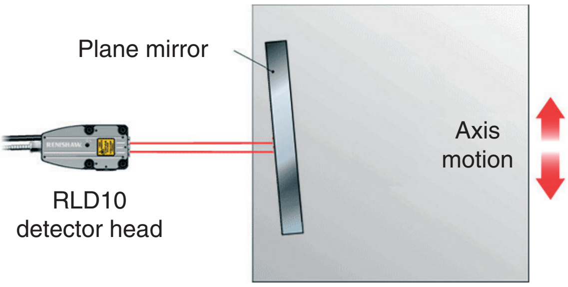
Surface quality is described using the military scratch and dig specification MIL-0-13830A, e.g. a 60 - 40 specification allows scratches of up to 60 µm in width and digs of up to 0.4 mm in diameter.

Renishaw recommends using a mirror with a scratch and dig specification of no more than 60 - 40. For a more detailed description of this specification, including maximum combined length figures, please contact your local Renishaw subsidiary or reference MIL-0-13830A.

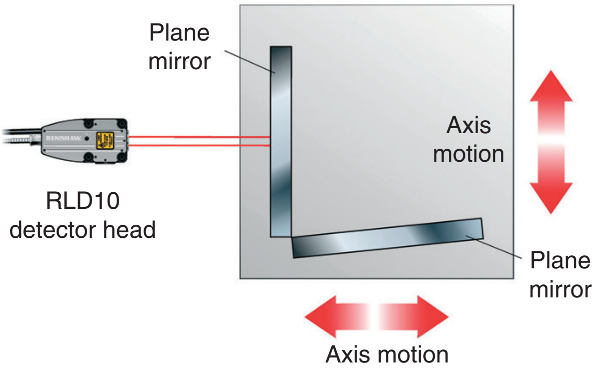
Mirror misalignment

The position of the motion platform is obtained by direct reference to the mirrors. If mirrors are properly aligned, linear errors which would normally result from mechanical deviations in straightness, orthogonality, pitch and yaw are removed (assuming no Abbé offsets are present). It is important to note that the accurate alignment of mirrors, or the use of L-mirrors, can produce a mirror system with a superior orthogonality to that of the stage axes.

Parallel error, caused when the mirror is not aligned properly to the axis motion.



Orthogonality error, caused when perpendicular mirror axes are not truly orthogonal to each other

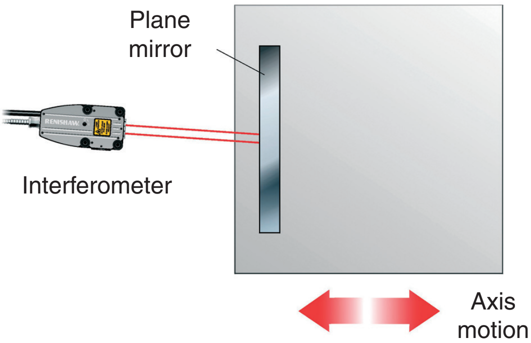


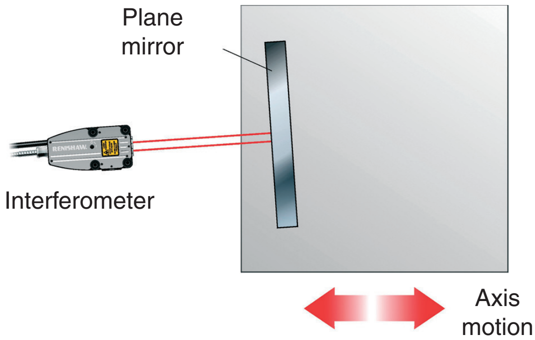
Parallel and orthogonality misalignment can cause errors of the magnitudes shown below:

Angular deviation Φ (arcsec)	Cross-axis error (ppm)	Measurement error* (µm)
0.5	2.4	0.7
1	4.8	1.5
2	9.7	3
3	14.5	4
4	19.4	6
5	24.2	7

* for a beam that has traversed 300 mm of the mirror length

Cosine error, caused when the mirror (and / or interferometer) is not perpendicular to the axis of motion





Cosine error = axis of motion length (1 - cosine Φ)

Angular deviation Φ (arcsec)	Measurement error* (nm)
5	0.09
10	0.4
20	1.4
30	3.2
40	5.6
50	8.8

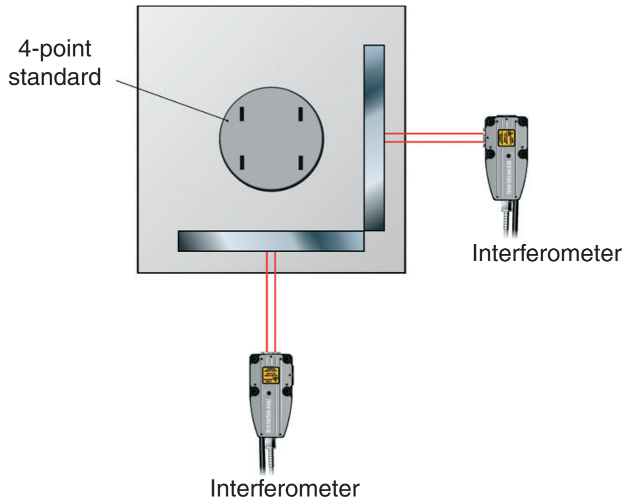
* for a stage that has travelled 300 mm

These errors can be overcome by:

- Carefully following a thorough alignment procedure
- Using a monolithic L-mirror with a high orthogonality specification instead of two stick mirrors.
- Aligning the system and then compensating for any errors through a correction table within the controller

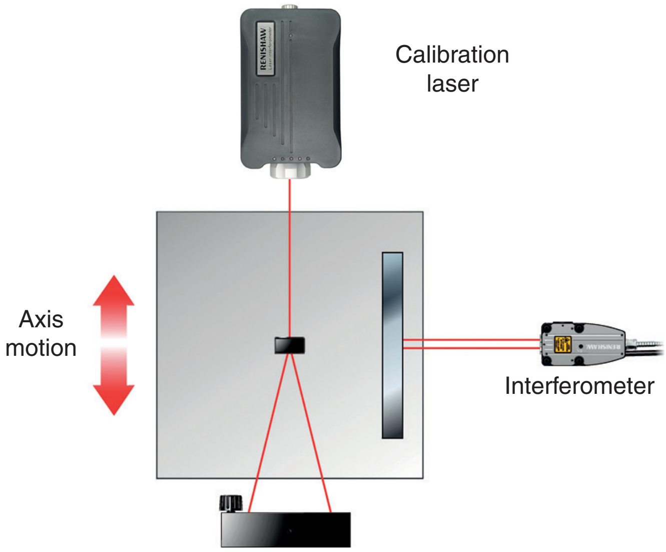
Error mapping - orthogonality

Orthogonality errors can sometimes be compensated for using the motion controller. A typical method to compensate for orthogonality is to map the system to a master on the stage e.g. a 4-point standard such as a wafer with calibrated fuducials. The master, in conjunction with a vision system, can be used to obtain the constants for a cross-axis algorithm that the motion controller can then apply to perform compensation.



Error mapping - mirror distortion

A typical method to compensate global flatness errors involves locking one axis in place and, using the stage interferometer and mirror, monitoring any cross axis displacement as the axis is traversed. At the same time the stage motion is monitored independently of the mirror for any way straightness deviations. If these two readings are subtracted from each other, any mechanical variations will be isolated from the mirror deformation, allowing the mirror's distortion profile to be calculated. Straightness can be monitored down to 0.5 µm using a calibration laser (or RLE with RLD10 XX detector head) and straightness optics.



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Products include:

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