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Mirror selection for optical periscopes

Overview

Renishaw differential interferometer detector head (RLD10-X3-DI) is sometimes required to work with larger beam separation between the measurement and reference beams. For these applications, Renishaw recommends the use of a periscope style assembly; however the specification of the mirrors within this assembly are critical and this application note highlights the reasons behind this.

Introducing additional optical components into the beam path will affect the amount of light that is returning to the detector within the head (also known as the signal strength). The RLD10-X3-DI uses polarised light; incorrectly specified mirrors within a periscope assembly can cause changes in the polarisation which in turn affects the signal strength.

This document focuses on the impact that polarisation phase shift may have on the signal strength if using incorrectly specified mirrors.

RLD10-X3-DI head

The design of the RLD10-X3-DI head utilises quarter-wave plates within the optical scheme; this is to ensure that light being returned is the correct polarisation. The beam splitter within the RLD10-X3-DI head is polarisation dependant and only accepts beams with the predefined polarisation.

Figure 1 below highlights the different laser polarisations along the beam path, both within the head and before the measurement mirror.

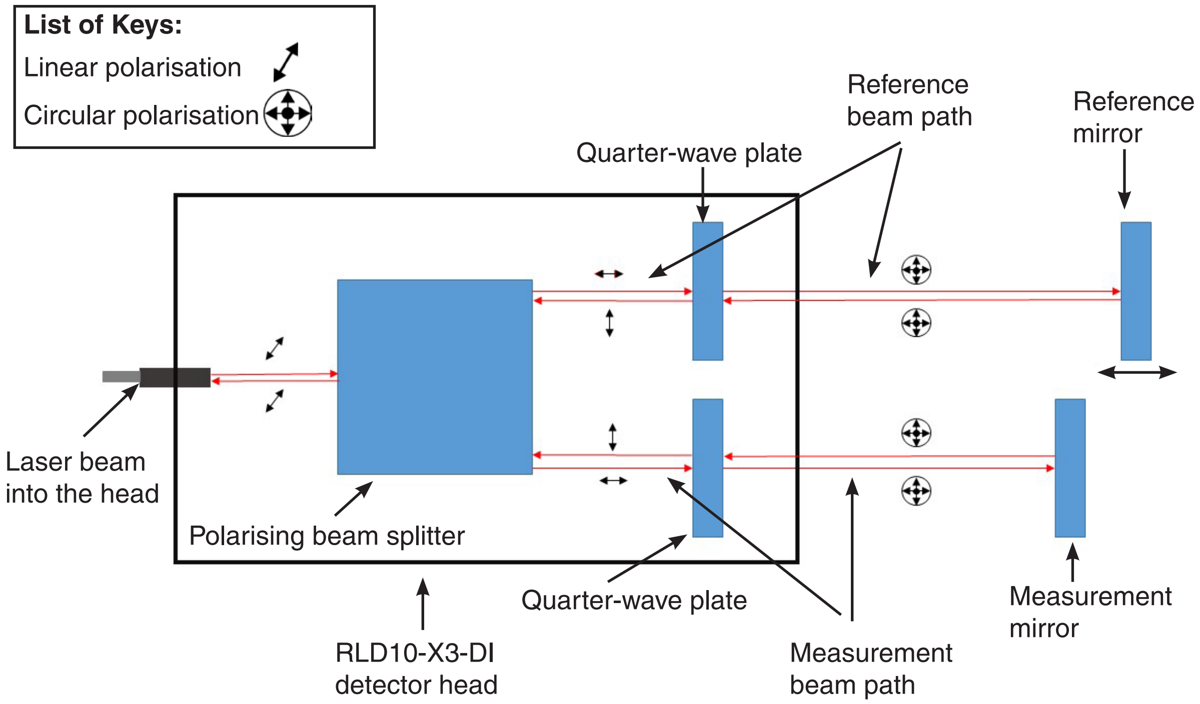

Figure 1: RLD10-X3-DI beam path

Application note

The beam is initially in a linear polarised state prior to it passing through the quarter-wave plate. Once it has passed through the quarter-wave plate, it becomes circularly polarised when leaving the head. When it passes back through the quarter-wave plate for the second time, after being reflected off either the measurement or reference mirror, it returns to being linearly polarised. For the second measurement path, it repeats this same process after passing around the interferometer and retro-reflector assembly.

When the RLD10-X3-DI head is used with a periscope assembly, there is the risk of incorrectly specified mirrors introducing phase shift into the laser beams. This phase shift then alters the polarisation of the laser beams, which means that when the light passes back into the detector head any distortion in the polarisation will be emitted by the quarter-wave plate. This emitted light then causes a reduction in the signal strength received by the detector head.

Effect of using a periscope

Using a typical periscope as an example, where the use of two 45° mirrors create a linear offset between the measurement and reference beams, similar to Renishaw's 15 mm periscope (A-5225-0634) as shown below in figure 2.

The RLD10-X3-DI is a double pass interferometer so the beams hit the measurement or reference mirror twice. Therefore the periscope mirrors a total of four times.

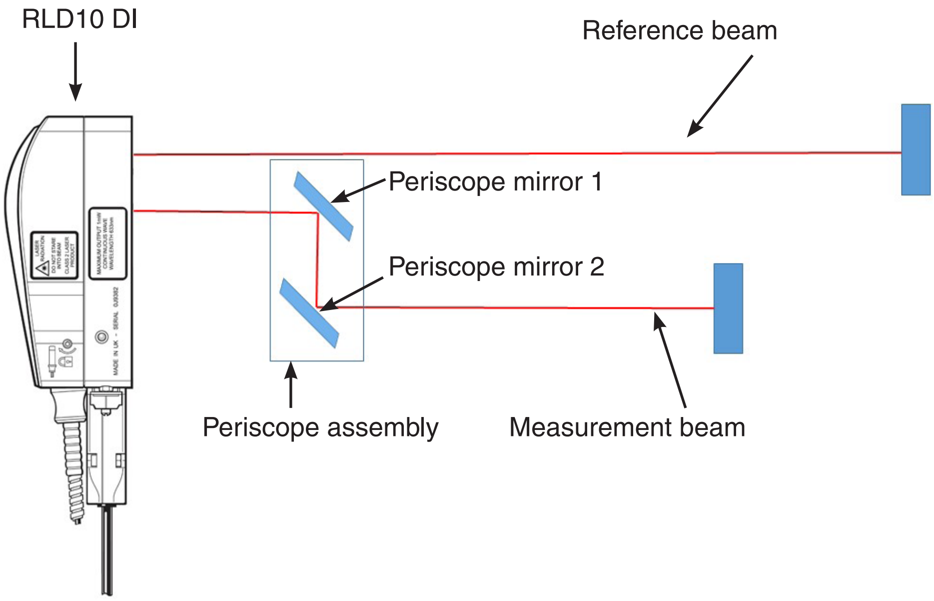

Figure 2: example periscope

As the measurement or reference beam from the RLD10-X3-DI head hits the periscope mirror a total of four times, any small change in phase shift can add up to a noticeable reduction in signal strength.

The signal strength is propotional to the square root of the multiplication of the change in laser intensity (also known as the laser power) of both the measurement and reference beams.

$$\text{Expected signal strength (\%)} = \frac{\sqrt{I_m I_R}}{I_o}$$

Where I_m and I_R refer to the laser intensity of the measurement and reference beam respectively and I_o is the initial laser intensity.

To better understand the impact of phase shift on the laser intensity and therefore signal strength, the model can be simplified to only include the quarter-wave plate and the periscope assembly polarising beam splitter modelled as a polariser. Figure 3 lays out the beam path of the double pass interferometer onto a simplified linear model.

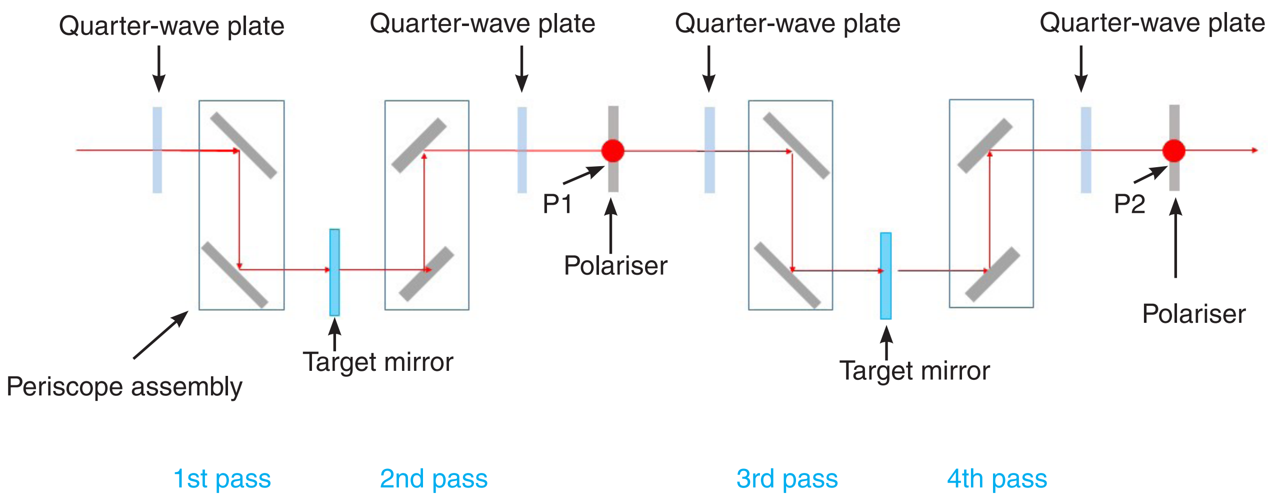

Figure 3: the simplified laser path model

The polarisation states can be analysed in two sections, P1 and P2, as the beam receives the same amount of polarisation distortion by passing through each of these two sections.

The beam is initially in a linear polarisation state before passing through the quarter-wave plate at 45° resulting in it being circularly polarised. It then passes through a periscope where the mirrors have amplitude reflectivity coefficients r_p and r_s. The difference in reflectivity is not what causes the phase difference, it is a separate quantity. E.g The mirrors also result in a phase difference of $\Delta\varphi$ between the *s* and *p* polarisations.

At P1 the polarisation state of the beam can be expressed using the following 'Jones matrix':

$$\begin{bmatrix}0 & 0\\0 & 1\end{bmatrix}\mathbf{R}\left(-\frac{\pi}{4}\right)\mathbf{M}_{QWP}\mathbf{R}\left(\frac{\pi}{4}\right)\mathbf{M}_{M}{}^{4}\mathbf{R}\left(-\frac{\pi}{4}\right)\mathbf{M}_{QWP}\mathbf{R}\left(\frac{\pi}{4}\right)\begin{bmatrix}1\\0\end{bmatrix}$$

Where the matrices are defined as follows:

$\mathbf{M_M} = \begin{bmatrix}r_s & 0\\0 & r_p e^{-i\Delta\varphi}\end{bmatrix}$ is the matrix for a mirror

$\mathbf{M}_{QWP} = \begin{bmatrix}1 & 0\\0 & i\end{bmatrix}$ is the matrix for a quarter-wave plate with its fast axis aligned to the horizontal

$\mathbf{R}$ (θ) is a rotation matrix by an angle θ

$\begin{bmatrix}1\\0\end{bmatrix}$ is the initial (horizontal) linear polarisation state of the beam

$\begin{bmatrix}0 & 0\\0 & 1\end{bmatrix}$ is the matrix for a polariser

To transform the matrix, the value of the laser intensity at P1 can be expressed in terms of the initial signal strength intensity:

$$I_{p1} = \frac{1}{4}\ I_O \left(r_p{}^8 + 2r_p{}^4 r_s{}^4 \sin(2\Delta\varphi) + r_s{}^8\right)$$

At point P2, the beam will have travelled through the periscope arrangement twice. The laser beam intensity is proportional to the square of the I_{p1} assuming there is no other signal strength loss. As the reference beam does not go through the periscope, the intensity of the reference beam is the same as the initial intesity.

$$I_{P2} = \left(\frac{I_{P1}}{I_O}\right)^2 I_O = \frac{1}{16} I_O \left(r_p{}^8 + 2r_p{}^4 r_s{}^4 \cos\left(4\Delta\varphi\right) + r_s{}^8\right)^2$$

$$I_m = I_{P2}$$

$$I_r = I_O$$

The expected signal strength can be determined by the equation below:

$$\text{Expected signal strength (\%)} = \frac{\sqrt{I_m I_R}}{I_O} = \frac{\sqrt{I_{P2} I_O}}{I_O} = \frac{1}{4} I_O \left(r_p{}^8 + 2r_p{}^4 r_s{}^4 \cos\left(4\Delta\varphi\right) + r_s{}^8\right) \text{x}100$$

Assuming the amplitude reflectivity coefficients r_p and r_s are equal, the expected signal strength (%) in relation to the phase shift and mirror reflectivity can be expressed in the diagram shown below.

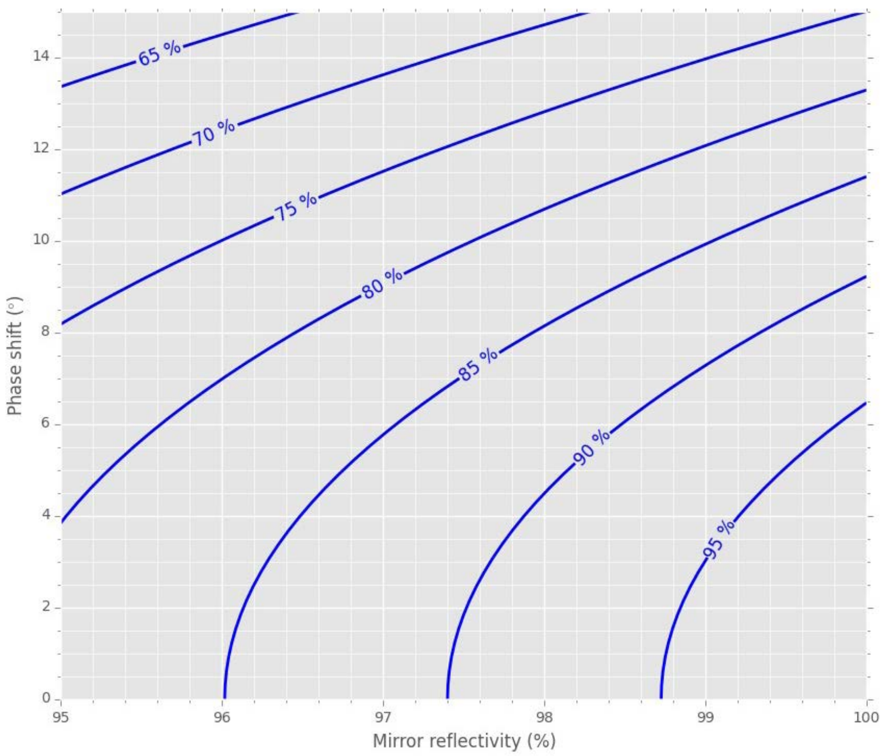

Figure 4: Signal strength in relation to the phase shift and mirror reflectivity

Figure 4 can be used as a guide when selecting mirror specifications based on the expected signal strength.

Example:

Using the mirrors with the following specifications:

- Phase shift: 6°
- Mirror reflectivity: 99.8%

The expected signal strength accounting the loss due to polarisation phase shift, can be roughly determined by drawing cross lines on the grid below, which is 95% as shown in figure 5.

Note: it is important to ensure that mirror specifications are quoted at an angle of incidence which is similar to how it will be used in the application.

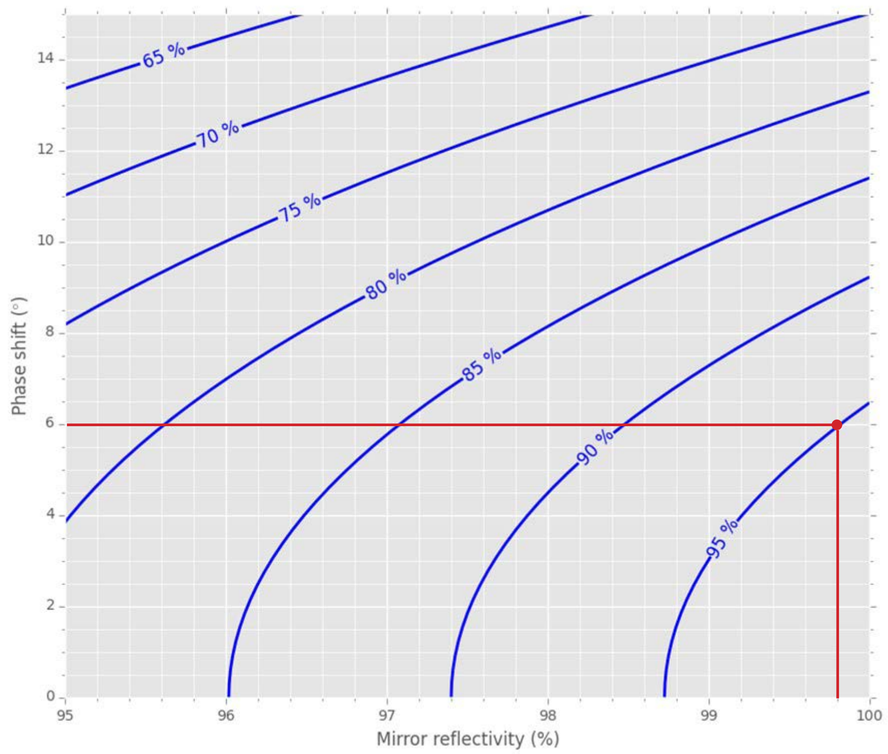

Figure 5: expected signal strength of a mirror with a reflectivity of 99.8% and phase shift of 6°.

Conclusion

When using periscopes in combination with the RLD-X3-DI head, it is important to ensure the phase shift of a mirror is considered as well as reflectivity. Small changes in phase shift compounded with multiple mirror passes can add up to significant reductions in signal strength.

When designing a periscope or additional mirrors into the beam path of the Renishaw detector head, it is critical the phase shift of the mirror at the incident angle of the beam is considered. This is to ensure the minimal loss in signal strength and therefore the highest performance.

Other factors that can affect signal stength

When working with, or designing periscopes, it is important to also consider the following factors:

- The alignment of the periscope optics
- The flatness of the mirrors
- Thermal movement of the periscope mirrors

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