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Phase Feedback Active Stabilisation of a Multiplexed Fibre Interferometer

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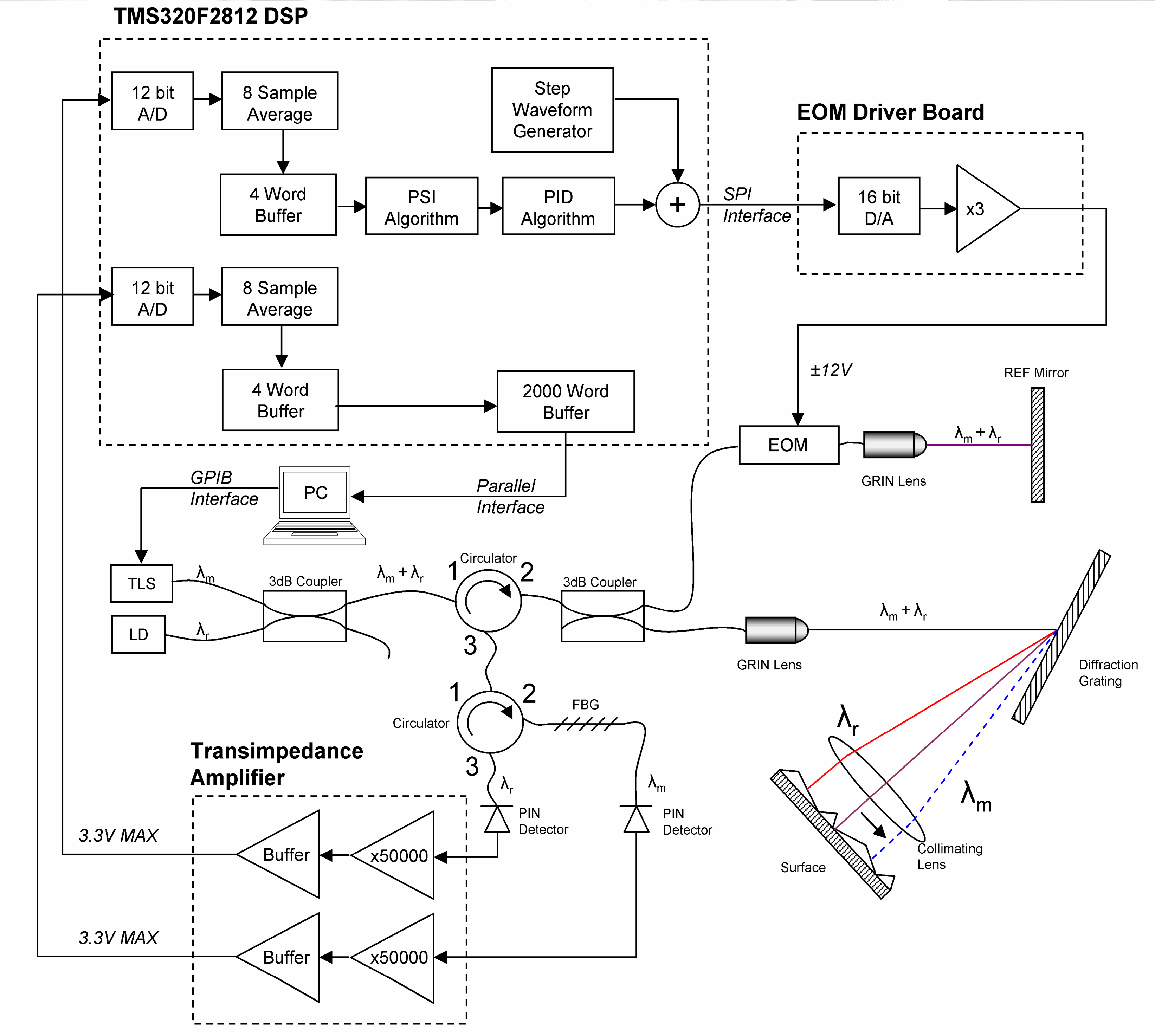
Introduction

Current optical technologies for surface measurement such as white light scanning interferometry (WLSI) can produce sub-nanometric resolution areal height information. However, the sensitivity of such devices to external vibration coupled with their bulky nature requires that any workpiece be removed from the manufacturing line in order for measurement to be taken place.

Clearly, a production line mountable, vibration stabilised device would provide benefits in manufacturing throughput and help reduce scrap rates. The multiplexed fibre interferometer (MFI) aims to provide this capability for high precision surfaces with sub-micron form deviation.

The MFI features profiling of a surface a fibre coupled remote mountable probe with no moving parts. It is capable a measuring a surface height profile with no moving parts.

The Multiplexed Fibre Interferometer (MFI)



The MFI is comprised of twin interferometers which are multiplexed into an optical fibre and share the same optical path for nearly all of their run. One interferometer runs from a fixed wavelength (λ_r=1550 nm) laser diode (LD) and measures any disturbance due to temperature fluctuation or external vibration.

The other interferometer runs from a tuneable laser source (TLS) and provides the actual measurement data. By using a blazed diffraction grating and harnessing the first order diffraction beam, the measurement beam is swept along a profile of the surface by altering the wavelength, λ_m between 1565 nm and 1580 nm.

A combination of circulators and a fibre Bragg grating (FBG) de-multiplexes the wavelengths from the two interferometers so their respective outputs may be monitored by separate laser diodes.

The response the interferometer phase, φ at a surface height at point *x* is governed by the following equation;

$$\varphi(x,t)=\frac{4\pi h(x)}{\lambda}+\varepsilon(t)$$

Where *h(x)* is the height of the surface above the point of zero optical path difference between the interferometers arm and *λ* is the operating wavelength. *ε(t)* represents a time varying drift of the optical path which is present in all fibre interferometers and must be considered an error term. The general relationship between the phase and the output intensity, *I* of the interferometer is shown below;

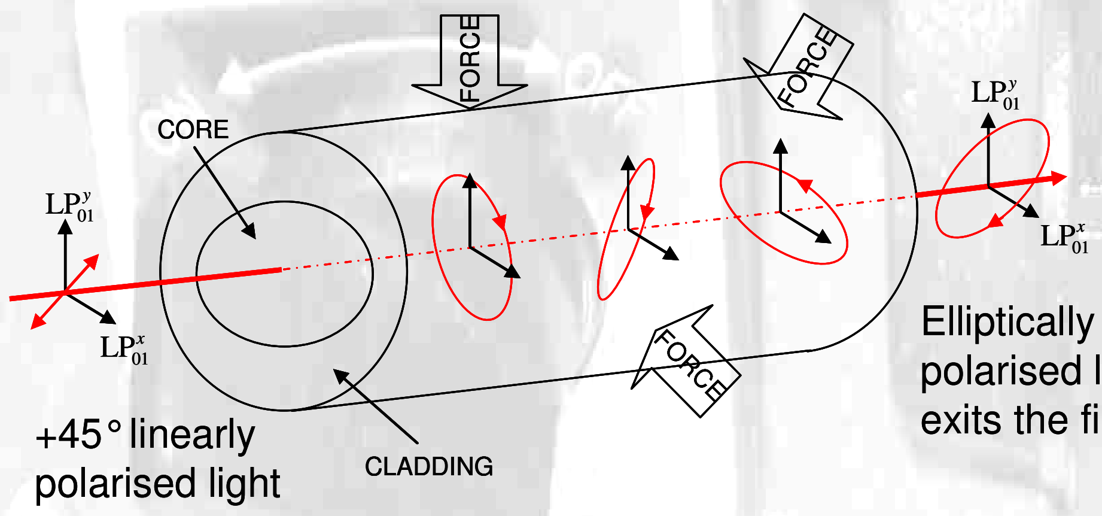
$$I=I_r(t)+I_m(t)+V(t)\sqrt{I_r(t)\cdot I_m(t)}\cdot\left[\cos\varphi(t)\right]$$

I_m and I_r are the intensities of the returning light in each arm of the interferometer and *V* is the fringe visibility (or contrast). These quantities fluctuate randomly with time.

In can be seen that the response is sinusoidal in nature and elements are time varying. The extraction of phase information from the intensity is thus not trivial.

The error term, *ε(t)* can run into several microns of path change in a few seconds, even for the 6 metres of fibre as found in this device.

In order to make this interferometer viable for nano-scale measurement it must be stabilised.



+45° linearly polarised light enters the fibre

Elliptically polarised light exits the fibre

The state of polarisation (SOP) of the light travelling through an optical fibre is constantly evolving as a result of birefringences induced in the core due to strains induced due to deformation of the core resulting from environmental effects. The mechanisms are similar to those which alter the path length.

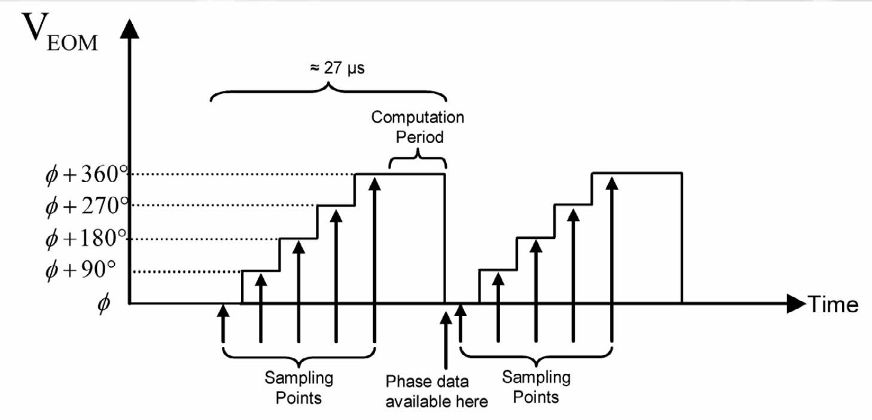
Changing SOP affects the intensity output in two ways; it changes the fringe visibility, *V* and also the absolute intensities, I_m and I_r in each of the arms due to the presence of polarisation dependant components (diffraction gratings, EOM).

The difficulty lies in stabilises the path length of the interferometer in the face of low frequency SOP disturbance.

Stabilising the Interferometer

An electro-optic phase modulator (EOM) can be used to alter the path length in the interferometer and has a very high frequency response. With no moving parts the path length is changed by harnessing the Pockels effect in which the refractive index of a crystal (Lithium Niobate, $LiNO_3$) is altered by the application of an electric field.

Rapid phase shifting using an EOM means that phase data may retrieved very rapidly from the interferometer. 5 phase shifts are need to calculate the phase from the intensity output. In this system the phase acquisition rate is around 37 kHz. The idea relies on the fact that phase shifts are carried out at such a rate intensity flicker due to low frequency SOP variation should be negligible between shifts.

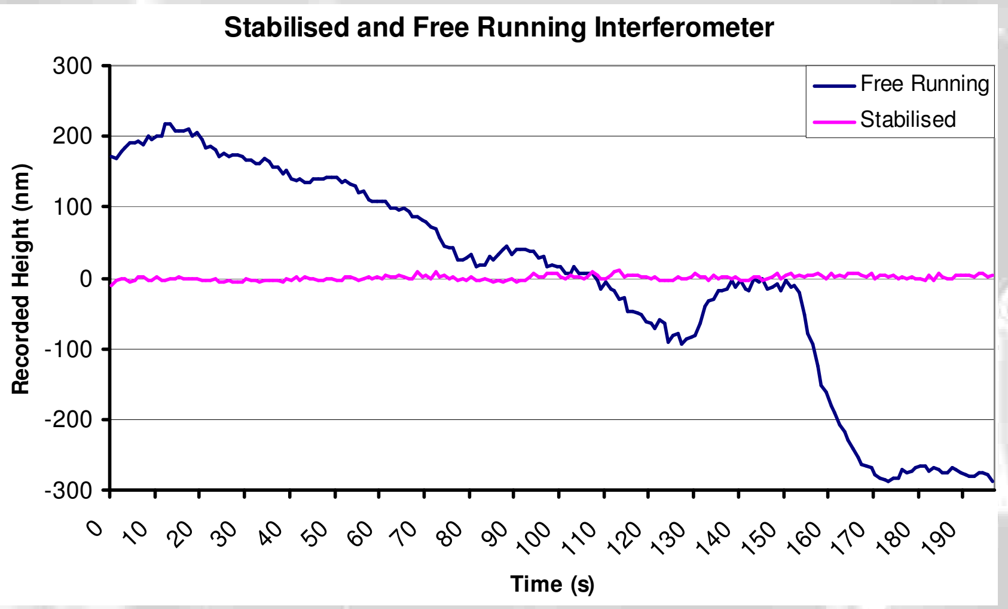


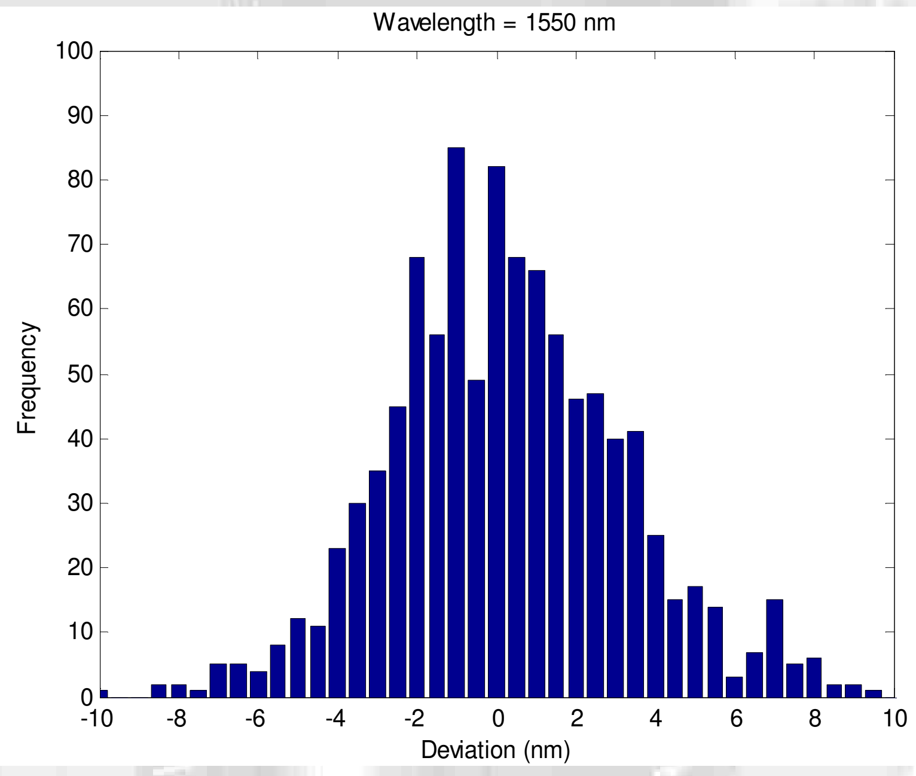
The phase shifting is carried out by applying a stepped waveform to the EOM (see left) . After the 5 shifts have carried out, the phase data is calculated by the DSP using the Schwider-Hariharan phase shifting algorithm.

The calculated phase then forms the feedback for closed loop control. The phase is adjusted by this loop simply by adjusting a DC bias of the phase stepping waveform. A PI control algorithm is digitally implemented on the DSP to provide this function.

Results

We see here the drift of the interferometer when it is free running and when the stabilisation control loop is active (see right). The drift in the free running interferometer is seen to be drastic and mainly the result of temperature variation. The improvement see in the locked interferometer is obvious.





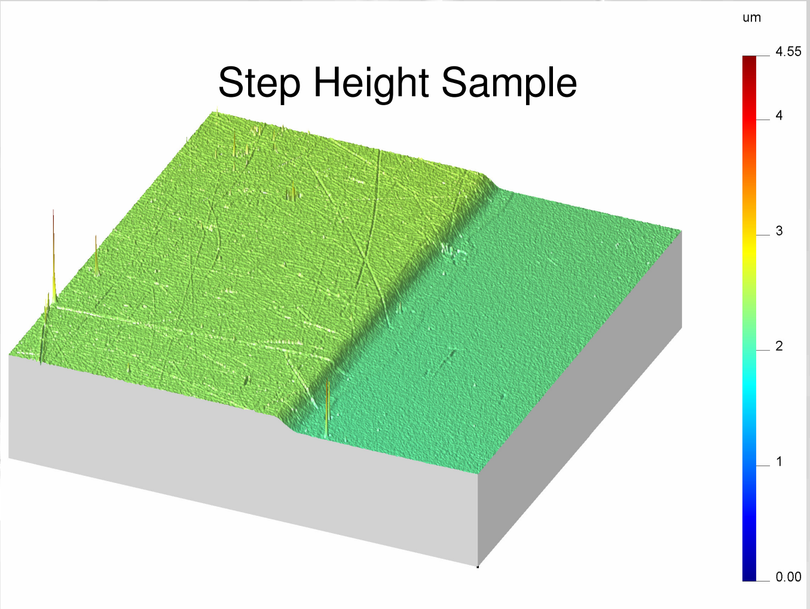
The repeatability of the instrument was investigated by measuring the response of the stabilised interferometer 1000 times.

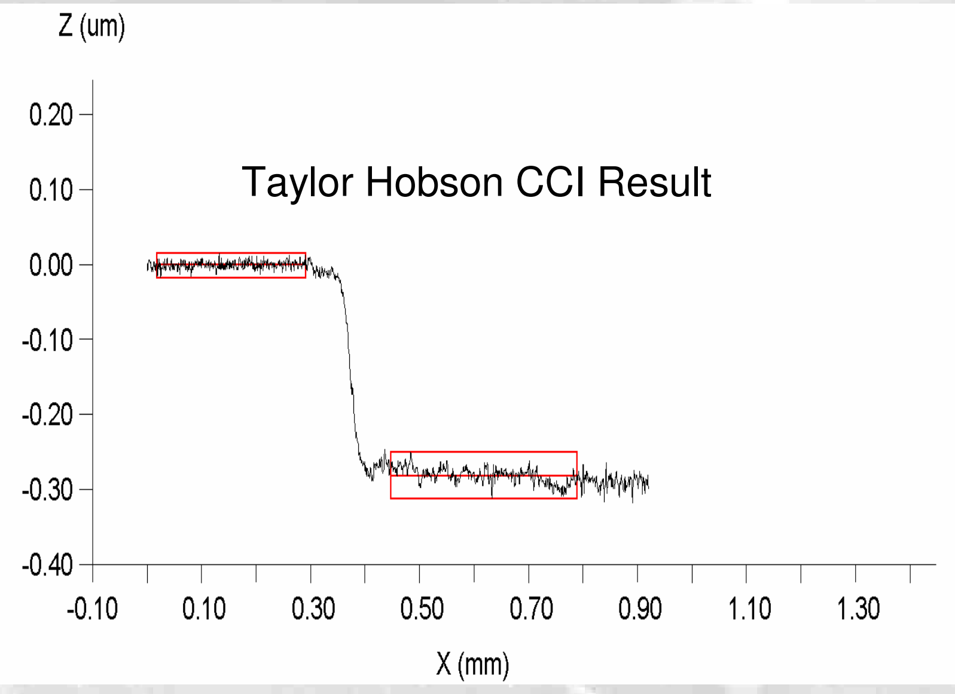
The histogram (see left) shows a normal distribution of values, the standard deviation being 2.98 nm.

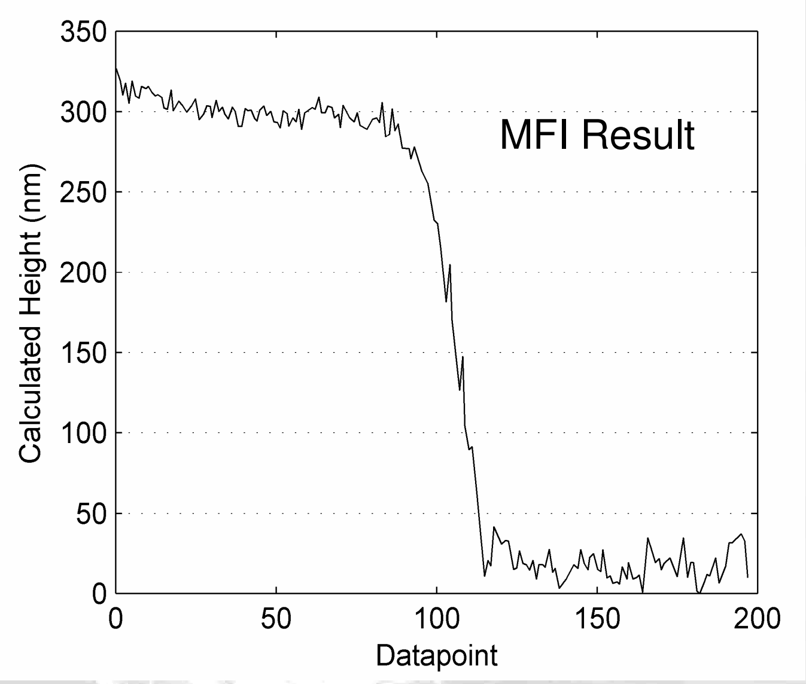
We can say with confidence that the interferometer is held within ±9 nm over 3 standard deviations from its target value.

To consider absolute accuracy, a step height sample was measured using commercial instrumentation (Taylor Hobson CCI) and compared with the result gained from the MFI.

A result of 285 nm is found to be in agreement between both instruments, certainly within the bounds of the surface roughness of the sample and the residual interferometer noise.







Acknowledgements and Further Reading

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- H. Martin, K. Wang and X. Jiang, “Vibration compensating beam scanning interferometer for surface measurement,” App. Opt. 47(7) (2008)