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A method for assessing measurement precision and stability of optical probes

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1. Introduction

Non-contact optical probes, such as chromatic probes, have potential to replace contact probes for some applications [1]. The use of non-contact probes in existing contact probe based systems could decrease measurement time and uncertainty [1]. Some optical probing techniques are capable of measuring non-specular metre-scale surfaces – for instance segmented freeform optics post-grinding – in the mid- to low-spatial frequency bandwidths (S-filter). Current measurement techniques use contact probe based systems where measurement precision is a limiting factor. State-of-the-art contact probes have a measurement uncertainty of 0.25 µm (2σ) [2] due to errors including: the probe-surface interface position, flexibility in the probe, and thermal expansion of the probe. Equivalent non-contact optical probes claim accuracies up to an order of magnitude higher [3]; employing these probes could therefore improve current measurement systems.

Two methods are presented: the first assesses the long term stability of a probe; whilst the second investigates the accuracy of a probe. These techniques contribute to the assessment of the viability of using chromatic probes in the measurement of large non-specular surfaces.

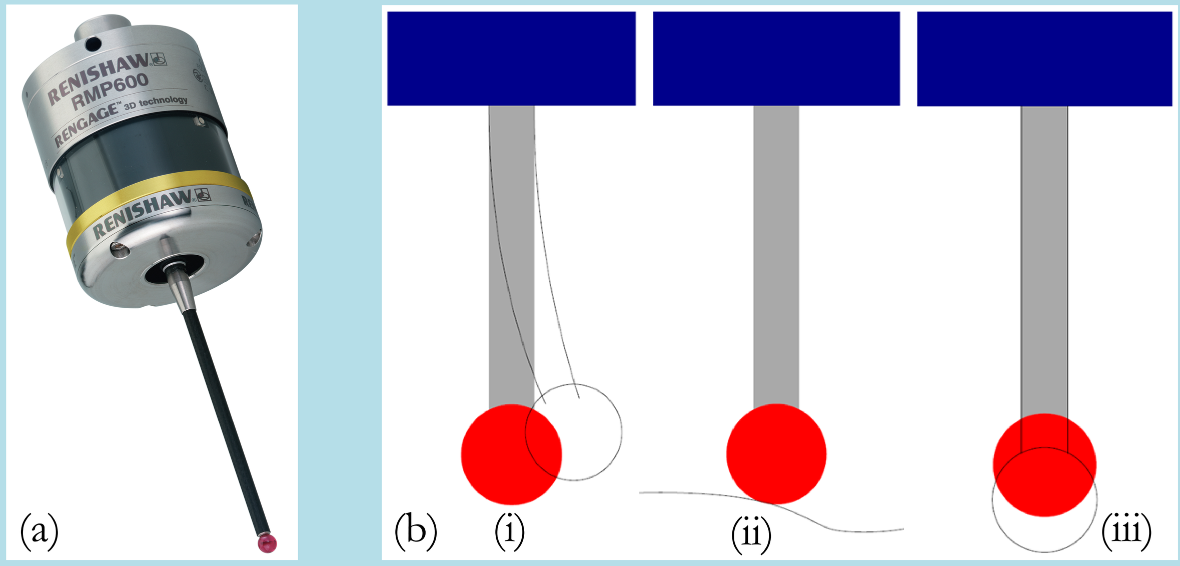


Figure 1. (a) Renishaw RMP600 contact probe [2]. (b) Three examples of errors that affect the measurement uncertainty of contact based probes: (i) illustrates the flexibility of a contact probe stylus, (ii) shows how the contact area between the probe and a surface is finite, and (iii) shows how the shape of a probe can change with temperature variation.

2. Probe stability and precision assessment

2.1 Measurement principle

A chromatic confocal probe measures the distance to a surface using the principle of axial chromatic dispersion within a single point optical sensor [1]. Figure 2 shows how an axial chromatic dispersion lens can be used to split the constituent wavelengths of white light, thus realising spectral encoding. Each wavelength of the light is focused at a different point along the axis of the lens corresponding to a point within the measuring range: the difference between the focal distance of the largest and the focal distance of the smallest wavelengths.

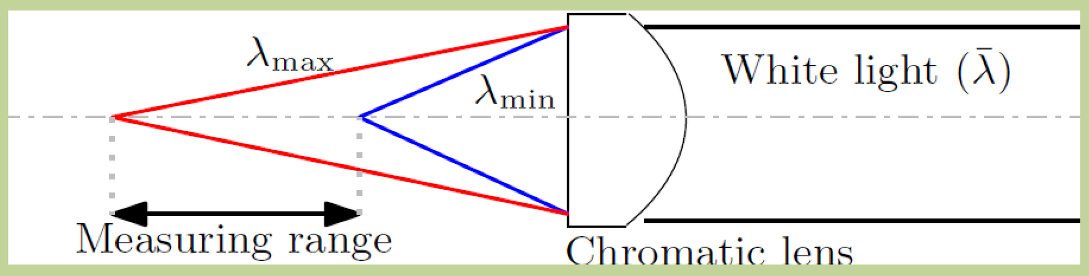


Figure 2. A white light source with wavelength range, λ, is directed into a chromatic lens and dispersed axially to generate a unique focal point for each wavelength [1].

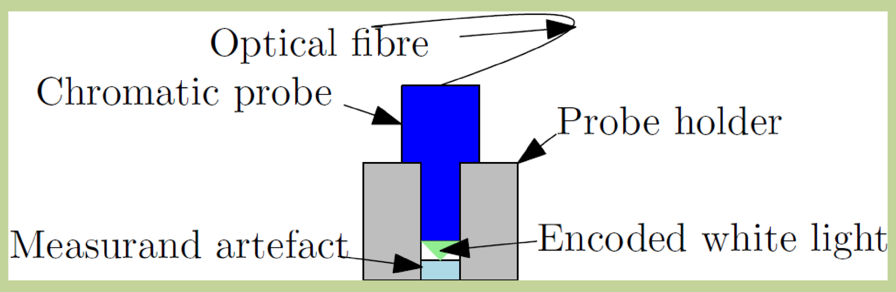


Figure 3. A chromatic probe held by a probe holder to measure a constant distance to the artefact surface.

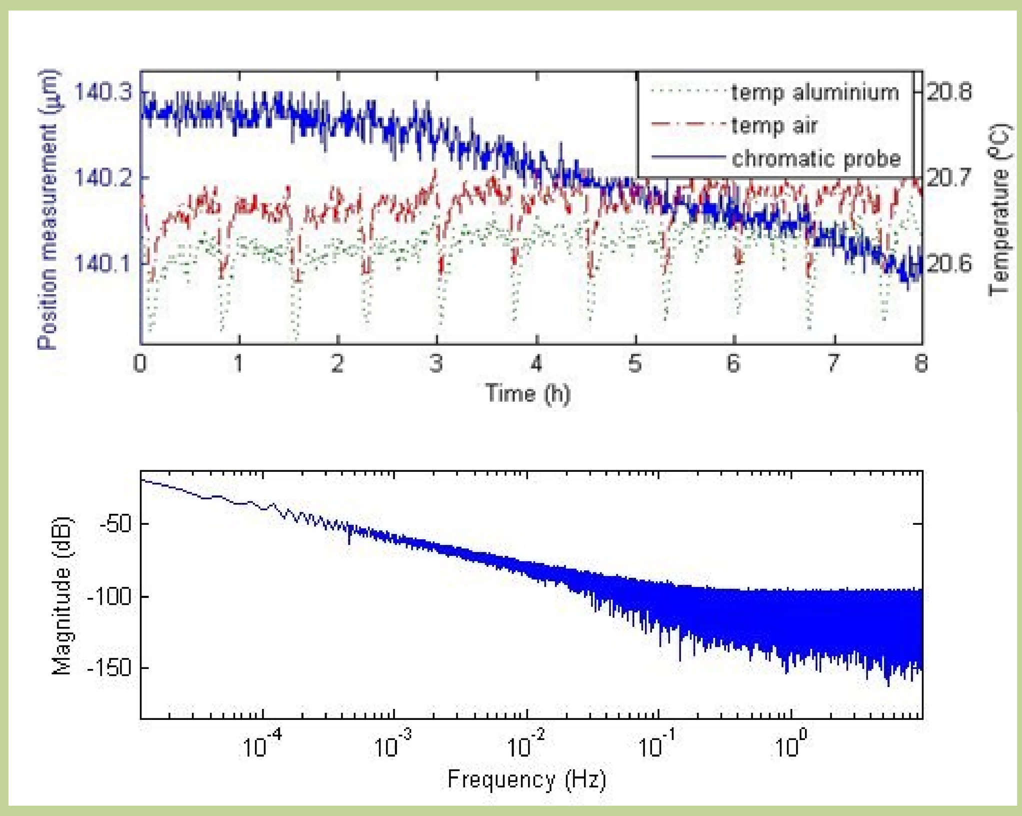
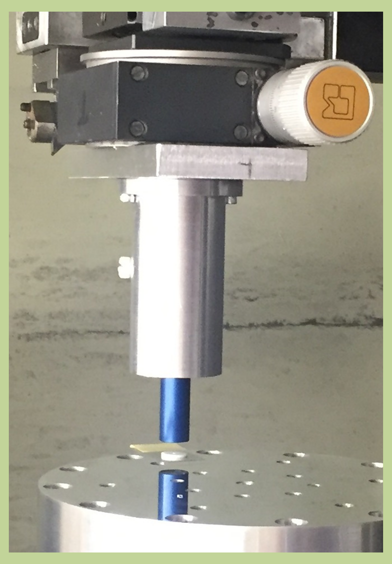


Figure 4. The position measurement of a chromatic probe over an eight hour period, the temperature of an aluminium probe holder, and air temperature (top) and fast Fourier transform of the measured position (bottom).

2.2 Stability evaluation test

The time to measure a metre-scale freeform surface is significant; thus a probe's stability should be analysed.

A CHRocodile SE 300 µm probe was held in a fixed position by an aluminium probe holder with a non-specular measurand surface placed within the probe's measurement range. The probe was stable to ± 20 nm during hours one and two; then changed linearly throughout the remaining measurement period by 200 ± 20 nm. The FFT in figure 4 shows low frequency changes in the position measured highlighting measurement instability. Investigation is required to determine the cause of these changes.



2.3 Accuracy testing

To validate whether a probe has the capability to measure a metre-scale freeform surface, assessment of the probe's measurement accuracy is required.

Figure 5. A CHRocodile SE 300 µm probe held with orientation control on a precision linear axis.

The probe was incrementally displaced along its measurement axis. Its position measurement was recorded and the deviation from the reference position calculated. The displacement was controlled on a 1D motion axis with < 2.4 nm sub-divisional error [4].

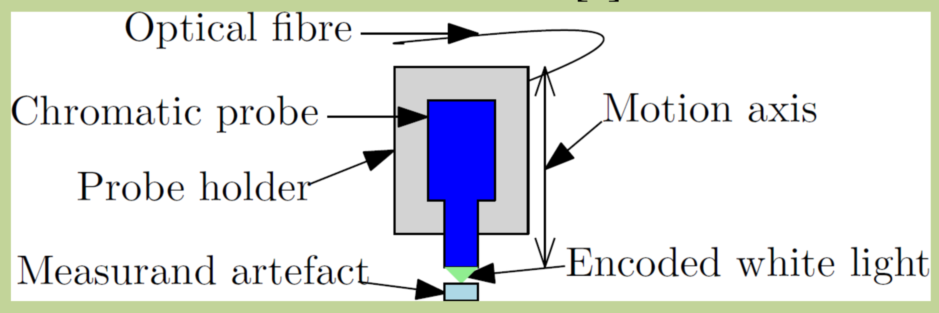


Figure 6. A chromatic probe held by a probe holder with orientation control set-up on a precision linear axis.

Figure 7 shows the difference between displacement measured by the probe and the reference position measured. As the probe was displaced through its measurement range from 10 µm to 15 µm and 290 µm to 285 µm the maximum deviation was 36 ± 4 nm and 85 ± 3 nm respectively.

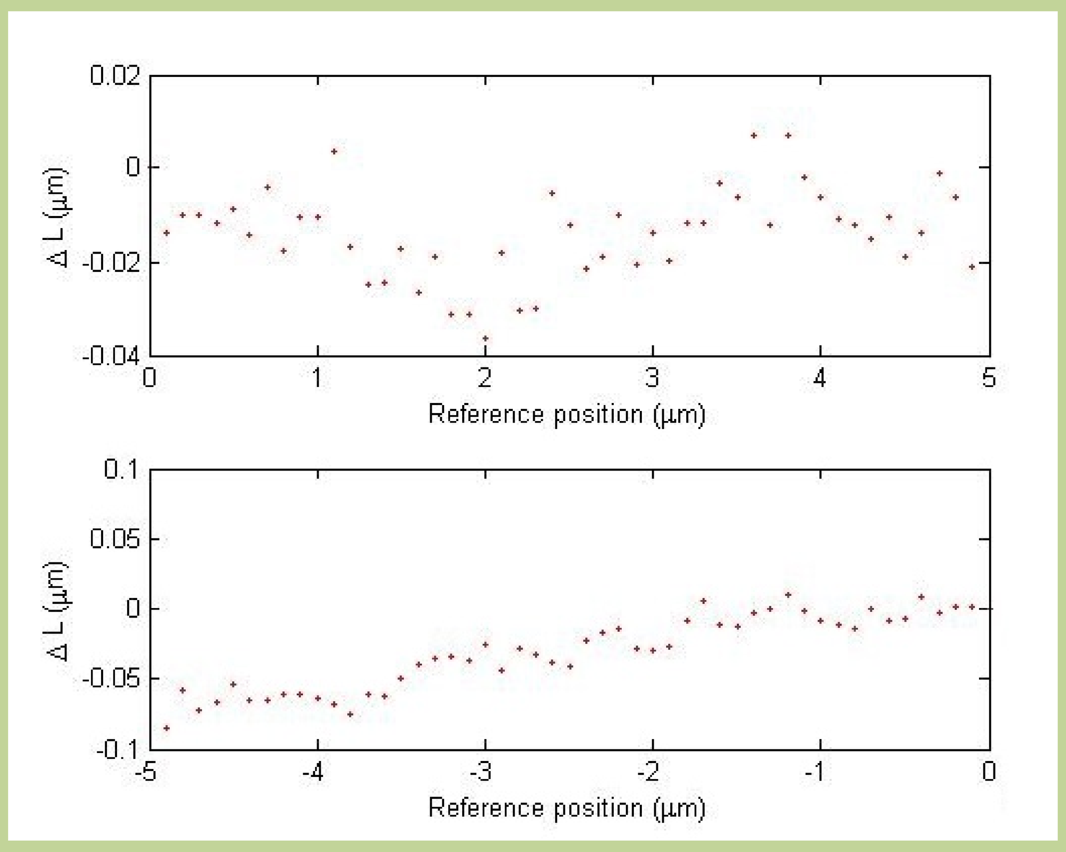


Figure 7. The difference between the displacement measured by the chromatic probe and the reference position measured by a precision motion system (ΔL), moving from 10 µm to 15 µm (top) and 290 µm to 285 µm (bottom) as measured by the probe.

3. Full measurement range assessment

Based on the results of the accuracy assessment detailed in section 2.3 the full measurement range of the chromatic probe was assessed using the same motion axis and measurand. The probe was positioned ~ 5 µm from the extreme of its measurement ranges and moved at 1 µm/s. The residual between the motion as dictated by the motion axis and the probes measured displacement for two opposing measurement run is shown in figure 8. The experiment was repeated multiple times in both directions. The maximum deviation from the reference position was ~ 2 µm and located at the end of the measurement run. This result is significantly larger than expected [3].

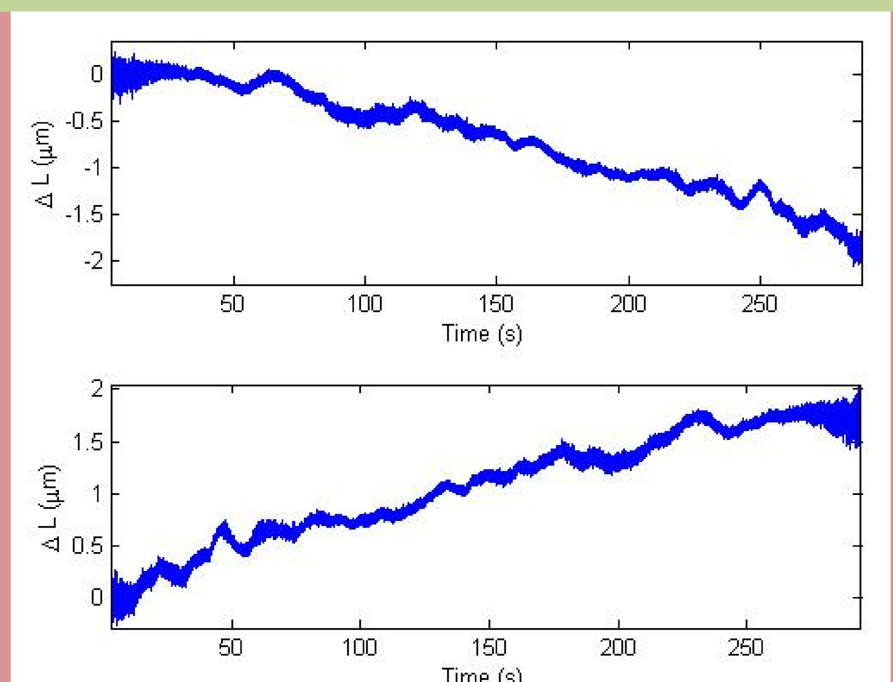


Figure 8. The difference between the probe measured displacement and the reference position (ΔL), 5 µm to 295 µm (top) and 295 µm to 5 µm (bottom) as measured by the probe.

4. Conclusion

The stability of a chromatic probe was 200 ± 20 nm over eight hour. The stability test should be thermally insulated for further investigation. Maximum deviation over a 5 µm displacement was 85 ± 3 nm. An assessment of the full measurement range showed a maximum deviation of ~ 2 µm. Further investigation is required to determine why this method of probe assessment produced results significantly larger than indicated by [3].

References

[1] Leach R. 2011, *Optical measurement of surface topography*, pages 71-106, Springer.
[2] RENISHAW. 2015, RMP600 high-accuracy touch probe.
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[4] Moore Nanotechnology Systems, Tec. Dept., Personal comm., 2016-4.

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