euspen's 17th International Conference & Exhibition, Hannover, DE, May 2017
www.euspen.eu

Surface roughness study on mirror finish surface products using patterned area illumination method

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Abstract
Mirror finish surface products are widely used in many industries such as aerospace, optics, semiconductor and biomedical device manufacturing. The surface roughness of mirror finish products are usually measured by off-line instruments such as coherence scanning or phase shifting interferometers which are time consuming and relatively difficult to integrate into the manufacturing equipment. In order to achieve both in-situ surface quality control and automated tool changing for the polishing process, accurate and real-time surface measurement are required. To address these in-situ measurement challenges, a surface roughness measurement system using the fringe pattern illumination method is proposed in this paper. By analysing the grayscale contrast ratio of the fringe pattern reflection image, the experimental results showed that the proposed system was able to measure different mirror finish surfaces with *Sq* from 10 nm to 165 nm. The experimental results demonstrated a good correlation between the grayscale contrast value and *Sq*. In addition, the grayscale contrast ratio was also correlated with directions of the machining marks and the projected fringes at different measurement angles. The surface texture aspect ratio parameter *Str* which provides information about the strength of the machining marks was experimentally evaluated and compared with grayscale contrast change. In conclusion, the proposed system was able to measure surface roughness and indicate machining pattern effects on the mirror finish surface.

Surface roughness, in-situ measurement, fringe pattern illumination, grayscale contrast evaluation

1. Introduction

According to ASTM standard A480 [1], mirror finish is a highly reflective, smooth finish typically produced by polishing with successively finer grit abrasives and finally with buff polishing. In recent years, mirror finish surface products have become more widely used in industries such as optical, semiconductor and medical device manufacturing resulting in new measurement challenges [2, 3]. Consequently research and development work has been undertaken to measure the surface roughness of mirror finish surface products in order to achieve in-situ surface quality control and automated tool changing for the polishing process [4, 5]. Contact based techniques (i.e. stylus profilometer) are not suitable for mirror finish surface measurement because the stylus tip may scratch the surface [6]. For mirror finish surface measurement, optical techniques such as confocal microscope, coherence scanning interferometer and phase shifting interferometer have great potential due to their non-contact mechanism to avoid both surface damage and contamination. However they typically suffer from relatively low measurement speed and are difficult to integrate into the polishing process [7]. Patterned area illumination method [8] is a new technique to evaluate the specular reflection and study the relationship between the surface roughness and gloss evaluation. In this paper, the developed patterned area illumination system and the referenced coherence scanning interferometer were used to measure the surface roughness of sixteen samples and the result data was compared and analysed. The experimental results showed the developed patterned area illumination system was able to measure the mirror finish surface roughness and indicate machining pattern effects on the mirror finish surface.

2. Materials and methods

Sixteen stainless steel samples labelled from A to P were ground and polished using BUEHLER™ EcoMet 300 Pro to achieve a range of surface roughness's *Sq* from 10 nm to 165 nm.

2.1. Coherence scanning interferometer

A Taylor Hobson™ Talysurf CCI HD with 20x objective was used as a reference instrument. It employs coherence scanning interferometry to measure the surface texture and is able to provide a spatial resolution of 1 µm and vertical resolution of 0.1 nm. Each sample was also measured five times with a measurement area of 2 mm × 2 mm. After form removal by third order polynomials, the root mean square roughness parameter *Sq* and texture aspect ratio parameter *Str* from ISO 25178-2 [9] were computed using the TalyMap software. The *Sq* parameter is the most common parameter to characterise optical surfaces as it can be related to the way that light is scattered from a surface. *Str* is one of the more suitable parameters when characterising a surface in an areal manner as it characterises the isotropy of the surface [10].

2.2. Patterned area illumination system

A patterned area illumination system was developed using a programmable illumination source and a monochrome machine vision camera. Figure 1 shows the system configuration. A black and white fringe pattern was generated by the illumination source. Reflected off the mirror finish surface, the image of the pattern can be captured by the machine vision camera. Michelson contrast is widely used for simple periodic patterns where both bright and dark features are equivalent [11]. The Michelson contrast is defined as equation (1).

$$C = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} \qquad (1)$$

L_{max} and L_{min} are the maximum and minimum luminance respectively in the image. However, the Michelson contrast is often influenced by the location of the distribution of grayscale level and the maximum or minimum value of brightness which is sometimes noise. In order to reduce the noise level, the grayscale contrast in the developed patterned area illumination algorithm was modified as equation (2).

$$C = \frac{AW - AB}{AW + AB} \qquad (2)$$

AB and AW are the average intensity of the white fringes and black fringes respectively. After analysing the greyscale contrast value of the fringe pattern image and the root mean surface roughness parameter *Sq*, a mathematical correlation can be determined. In addition, the test samples were rotated by 10 degrees from 0 degree to 180 degree. The grayscale contrast difference caused by changing the measurement angles was compared and analysed with texture aspect ratio parameter *Str*.

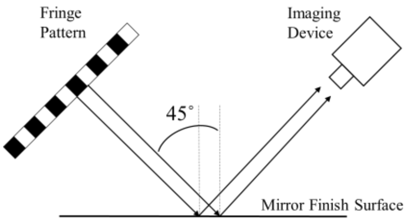

Figure 1. Model illustration of the patterned area illumination system

3. Results

A plot of the *Sq*-contrast curve is shown in Figure 2. The results show good capability of the proposed system for surface roughness measurement. As widely accepted, the coefficient of determination R^2 value indicates how well data points agree with the fitted line. The high R^2 value of 0.9819 in the *Sq*-contrast curve indicates that linear regression of the data set is reliable. Based on the *Sq* and contrast value in Figure 2, a linear relation can be modelled as equation (3).

$$S_q = -175.29C + 165.84 \qquad (3)$$

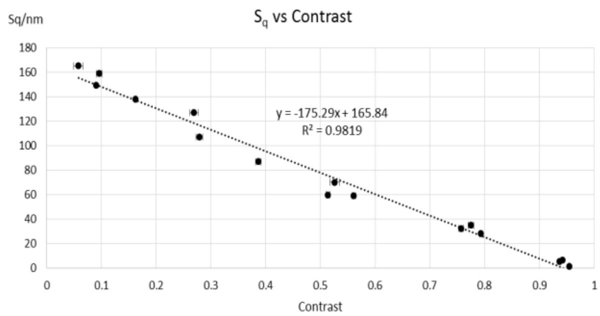

Figure 2. *Sq*-Contrast curve

Sample B and sample H shown in Figure 3 were chosen to study the effect of machining pattern on mirror surface isotropy. These two samples represent two typical mirror finish surface with unidirectional machining pattern and multi-directional machining pattern. They have a very close *Sq* value (mean ± st.dev) of 59.3 ± 1.3 nm and 60.1 ±0.4 nm respectively. But the *Str* value of sample B and sample H is 0.072 ± 0.006 and 0.426 ± 0.013. In principle, *Str* has a value between 0 and 1. Larger values, say *Str* > 0.5, indicates uniform texture in all directions. Smaller values, say *Str* < 0.3, indicates an increasingly strong directional structure or machining pattern. Sample B and sample H are typical examples of surfaces with similar *Sq* values but having different surface uniformity. The contrast values at different measurement angles for sample B and sample H were plotted in Figure 4 to compare the grayscale contrast difference. The grayscale contrast value at 0 degree and 180 degree is much larger than those at the other measurement angles for sample B. As a comparison, sample H has random and similar grayscale contrast value from 0 degrees to 180 degrees. Other samples have a similar trend that the samples with *Str* value close to zero have two peak in 0 degree and 180 degree. Based on these observations, the proposed area illumination system indicate machining pattern effects on the mirror finish surface.

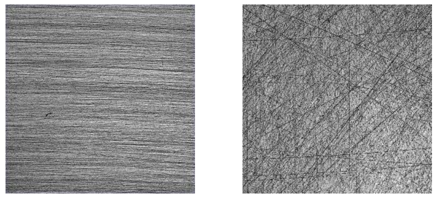

Figure 3. Sample B and sample H

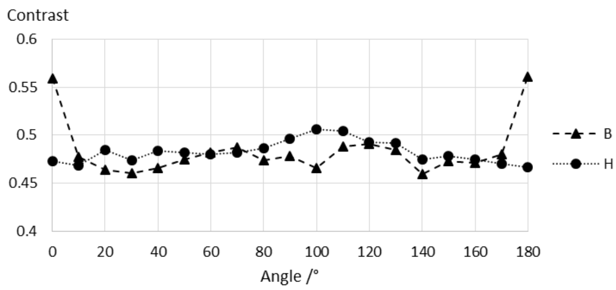

Figure 4. Contrast value in different measurement angles

4. Conclusion and future work

The developed patterned area illumination system and the referenced coherence scanning interferometer were used to measure the surface roughness of the sixteen mirror finish surface samples and the results were compared and analysed. The good linear relation between *Sq* and grayscale contrast showed the developed patterned area illumination system was able to measure the mirror finish surface roughness in the *Sq* range of 10 nm to 165 nm. The different grayscale contrast values at different measurement angles are able to indicate machining pattern effects on the mirror finish surface. Future work is in progress to new fringe pattern to study the two directional grayscale contrast change and the surface texture aspect ratio parameter *Str* in 360 degree measurement.

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