Evaluation of roughness of machined surfaces using vision system by phase shifting method

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Abstract

Evaluation of surface roughness has assumed considerable significance due to the better understanding of its role on the performance of the components. To overcome some of the drawbacks of the stylus method, optical methods were developed, which include using principle of interferometry. In this work an attempt is made to evaluate the surface roughness of machined surfaces by phase shifting method.

Key words

Vision inspection, Roughness evaluation, Phase shifting method.

1. INTRODUCTION

Surface roughness evaluation has assumed considerable significance due to better understanding of its role on the performance of the component. The most popular method of surface roughness evaluation is by stylus method. The stylus method is

contact in nature which has a limitation in measuring speed. In order to overcome some of the drawbacks of the stylus method, other methods were developed and most of them are optical. The electro-optical methods though fast do not provide enough information for the full characterisation of the surface.

One of the methods employed widely for the surface roughness assessment is by using the principle of interference of light. Interferometry produces interference fringe pattern when two or more light waves combine in phase after travelling different path lengths. Interact with each other. Traditionally, interferometry has been used to determine surface roughness (Bruning, *et al.*, 1974; Bennett, 1976; Cheng and Wyant, 1985; Ai and Wyant, 1987; Larkin and Oreb, 1992) and construct the topography of the surface. The reconstruction of the surface topography from fringe patterns has been accomplished by several different methods. Perry *et al.* (1983) created the topographic map of the surface using the undulations of the fringe centre lines. Bruning *et al.* (1974) introduced the phase shift interferometry which uses surface reconstruction method. The phase shift of each point on the fringe is calculated and converted into height thus creating the topographic map of the surface.

Many phase shifting algorithms that perform well with sinusoidal or near sinusoidal periodic wave fronts have been developed (Gierloff, 1987). In this work an attempt is made to evaluate the surface roughness by phase shifting method. A vision system is used to grab and analyse the fringe patterns. It is different from the previous methods in that the method does not use complex optical set-ups. Moreover the conventional interferometric measurements are restricted to highly reflecting surfaces.

2. PRINCIPLE

The interference concept is based on the superposition property of the coherent light waves. For example, if two waves of initial amplitudes 'a' and 'b' with the same wavelength ' λ ' leave a source and travel by different paths and then arrive at the same point in space, where superposition occurs, the complex amplitudes of the resultant waves is given by the sum of the complex amplitudes of the initial waves. Consider two wave trains ' E_1 ' and ' E_2 ' that are given by

$$E_1(x,y) = ae^{2ikl} \quad (1)$$

$$E_2(x,y) = be^{2ikw(x,y)} \quad (2)$$

where a and b denote the wavefront amplitudes and

$$k = \frac{2\pi}{\lambda} \quad (3)$$

where, 'k' is the wave number and ' λ ' is the wave length of light.

'l' is the mean path length from the reference surface and the 'w(x,y)' is the mean path length of the test surface. These two waves join together and produces the resultant wave 'E_p', which is given as

$$E_p(x, y) = E_1(x, y) + E_2(x, y) \quad (4)$$

The energy flux or intensity of a wave is proportional to the square of the amplitude of the wave field or $E_p * E_p^*$, E_p^* is the complex conjugate of E_p . From this the intensity distribution in the interference pattern is given as

$$I(x, y) = A + B \cos(\phi(x, y) + \alpha) \quad (5)$$

where, 'A' is an unknown constant due to background intensity, 'B' is an unknown constant due to fringe contrast, ' ϕ ' is the required phase difference and ' α ' is the added phase difference.

The intensity distribution, I, can be used to reconstruct the surface topography of the specimen. For each position (x,y) in the interference pattern, the phase or the wavefront that corresponds to the surface height w(x,y) can be found within some multiple of 2π .

$$\phi(x, y) = \arctan \left[\frac{I_4(x, y) - I_2(x, y)}{I_1(x, y) - I_3(x, y)} \right] \quad (6)$$

Since the phase $\phi(x, y)$ is determined by using an arctangent function, it is restricted between $-\pi$ and π . Hence a consistency may arise in determining the fringe order. This constitutes the unwrapping phase problem, which is important in digital fringe analysis (Bone, 1991; Asundi and Chan, 1994). The one dimensional phase unwrapping problem is simpler. These algorithms have been extended to two dimensions (Macy, 1983). They are based on addition or subtraction of 2π when the phase difference between the two adjacent points is greater than π . First, each row is scanned and then the process is repeated into each column and depth of surface points is calculated using the following equation.

$$Depth = \frac{p}{2\pi} \left[\frac{\phi_{obj} - \phi_{ref}}{\tan \theta} \right] \quad (7)$$

Where 'p' is the pitch and ' θ ' is the angle of projection.

3. EXPERIMENTAL PROCEDURE

In this method a micro computer based vision system is used for image acquisition and analysis. In the measurement process, a projector is used to project a computer generated grating pattern onto the surface to be inspected. The pitch and the type of the intensity distribution can be varied using a software. Specimens are made to varied roughness by different manufacturing processes, which include shaping, milling, EDM, casting and sandblasting. The specimens are made to different roughness by using different machining parameters (speed, feed and depth of cut). Figure 1 shows the images of the different specimens used in the experiment.

Figure 2 shows the experimental set-up. The specimen to be inspected is kept in position and is illuminated using grating projector at 45 degrees. The projected pattern will be deformed in accordance with the surface irregularities. The deformed grating pattern is captured using a CCD camera. Figure 3 shows the projected grating patterns on sand blasted surfaces as seen through the CCD camera.

The digitised image is stored in one of the four frame buffers. The specimen to be inspected is then moved by distances equal to $p/4$, $p/8$ and $p/16$. where 'p' is the pitch of the grating. Thus in all four images are grabbed. The specimen is then replaced with the reference surface and the above procedure is repeated. Thus, in all, eight images are grabbed. The algorithm will then compute the phase values at each pixel within a window of 32×32 pixels.

4. PHASE UNWRAPPING PROCEDURE

Since the phase is determined using an arctangent function it is restricted between $-\pi$ and π . Hence, a consistency is maintained in determining the fringe order. This constitutes the unwrapping phase problem, which is of interest in digital fringe analysis.

A serious problem confronting all the phase shifting techniques is the phase unwrapping after arctangent calculations. If each phase point is unwrapped along some fixed direction, it always propagates errors from bad quality points to good quality points. The method of phase unwrapping is known as ordered phase unwrapping procedure. For such processing it needs quality factor in determining the quality point (Q). Quality factor is defined as

$$Q_i = \sum_{m=1}^4 |P_m - P_i| \quad (8)$$

where ' Q_i ' is the quality factor of phase point ' P_i ' and ' P_m ' is the one of four adjacent points around ' P_i '. While getting the absolute phase differences, the

(a) Shaped surface

(b) EDM Surface

(c) Milled surface

(d) Sand blasted Surface

Figure 1 Different texture images.

Figure 2 Experimental set-up.

(a)

(b)

(c)

(d)

Figure 3 Projected grating pattern on a typical sandblasted surface.

2π jumps should be excluded, if they exist. With the quality factor, an optimal order for unwrapping all the phase points can be determined automatically and the propagation of the errors can be kept as low as possible. In order to get results, representing the good phase points, bad region recognition can be performed on the $-\pi$ and π wrapped phase map. It is because, no fringe areas and the poor quality fringe areas are most obvious during processing. The main feature in the wrapped phase maps is the phase values jumping randomly in high spatial frequency. So a rectangular region around an inspected phase point is selected and the surrounding points whose phase differences to the inspecting point satisfying the following conditions are encountered. The condition is given as

$$\delta p < |P - P_0| < 2\pi - \delta p \quad (9)$$

Where 'P' is the phase point in the surrounding area, 'P₀' is the inspected phase point and δp is the allowance of legal amplitude of phase variations. If the number counted is greater than the given threshold, the inspected point will be marked as a bad point and will not be processed during phase unwrapping.

5. RESULTS AND DISCUSSIONS

The software computes the depth of the surface points using the equation (7) and plots it as a 3D plot. Figure 4 shows the 3D plots of machined surfaces.

1. Specimens are made to different roughness by different manufacturing processes. They are made of shaping, milling, EDM and sandblasting processes. It was found that there was a good correlation between the average roughness and those computed from vision methods. Figure 5 shows the correlation between the vision roughness and the average roughness obtained from the stylus instrument.
2. The method is fast in computing surface roughness parameter and is applicable for on-line inspection of surface roughness. The method can be used to evaluate the surface roughness of rough surfaces. These include surfaces made of milling, shaping, EDM, sand blasting, and casting processes.
3. The accuracy of the proposed method depends on the pitch of the grating used. The smaller the pitch the better will be the accuracy. The equation for computing the phase values is derived with the assumption of the sinusoidal intensity distribution. In reality, the actual profile is not truly sinusoidal. The effect of the non sinusoidal intensity distribution on the computed values will be minimised by using the grating of smaller pitch.

Figure 4 3D plots of typical (a) cast (b) EDM and (c) sandblasted surface.

4. Coefficient of variation increases with decreasing roughness, suggesting that the method is not applicable for smooth surfaces. Accuracy of measurement can be improved by using the Liquid Crystal Display (L.C.D) Projector.

Figure 5 Correlation curve of shaped surfaces.

6. CONCLUSIONS

In this work an attempt is made to evaluate the surface roughness of machined surfaces by phase shifting method. A micro computer based vision system is used for surface image acquisition and analysis. Phase values are computed using the bucket equation. The unwrapped phase values are then used to compute the depth of the surface points. It was found that there was a good correlation between the average roughness and the vision roughness computed from the vision method. The method is quick, reliable and finds application in high speed and automated inspection of machined surfaces.

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