An application of reflective holographic gratings for measurement of cylindrical curvature

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Abstract. This paper presented an application of reflective holographic gratings for the measurement of cylindrical curvature. The surface of the fabricated holographic grating was coated with gold by the sputtering method, where it became a reflective holographic grating. The grating was attached to the surface of various radius cylindrical objects. The diffraction pattern produced by the bent grating with different radius was observed by illuminating a laser beam normal to the grating surface. The gratings constant were calculated from the observed diffraction pattern. The relationship between the grating constants and the radius of cylindrical objects was obtained. The grating constant and the reciprocal of the radius of cylindrical objects was a linear relationship, with the least R-square between 0.85-0.97. Moreover, the y-intercept of the relationship between the grating constants and the reciprocal radius was consistent with the grating constant of the non-bended grating. As the radius of the grating approach is infinite, the reciprocal of the radius approaches zero, which is a non-bend grating. We can apply this method to measure the radius of cylindrical objects.

1. Introduction

Curvature is an important physical parameter that needs to be monitored in engineering, bridge, machinery, architectural structure, health monitoring, biomechanics, robotics, and aerospace. Various optical fiber-based curvature sensors have been widely studied due to their distinct advantages of simple structure and high sensitivity. Researchers have proposed methods for the physical parameter based on a different structure, such as holographic optical elements (HOEs) [1], long-period grating (LPG) [2–3], fiber Bragg grating (FBG) [4–7], photonic crystal fiber (PCF) [8–9], a multicore fiber (MCF) [10–11], and in-fiber Mach–Zehnder interferometer (MZI) [12–14]. They could be well applied to the physical parameter measurement. However, the methods mentioned above have some accuracy problems and complication for setting up.

This research proposes a method for measuring the radius of cylindrical objects by applying reflective holographic gratings. The reflective holographic grating was fabricated by the method in Ref. [15]. Then, the holographic grating was coated with gold by the sputtering method. The grating was attached to the surface of various radius cylindrical objects. A diffraction pattern appears on the screen observed by illuminating a laser beam normal to the bent grating surface. The grating constant is calculated from the diffraction pattern where the grating constant corresponds to the radius. Then grating constant is confirmed by Scanning Electron Microscope (SEM). The relationship between the gratings constant and the reciprocal radius of the objects and discussed. Using this method, the radius of a cylindrical object could easily be measured, uncomplicated experiment setup and able to measure the radius in a narrow space. In the future, we may have more devices to support better measurement.

2. Experiment

2.1. Fabrication of reflective holographic grating

Transmission grating fabricated from an alternative setting of Michelson interferometer, Inneam *et al.* [15], were fabricated. By adjusting the angles between the two arms of the Michelson interferometer, cross-beam angle, we can obtain a fringe pattern that has a linear shape. The grating sample 1 to 5 have cross-beam angles (β) 0.2°, 0.4°, 0.6°, 0.8°, and 1.0° respectively. The surface of the fabricated holographic grating was coated with gold by the sputtering method. The sputtering method used gold as a target material bombarded with the Argon plasma, the plasma current of 18 mA in 120 s, and the coating thickness is 408 Å. The transmission grating became the reflective holographic grating.

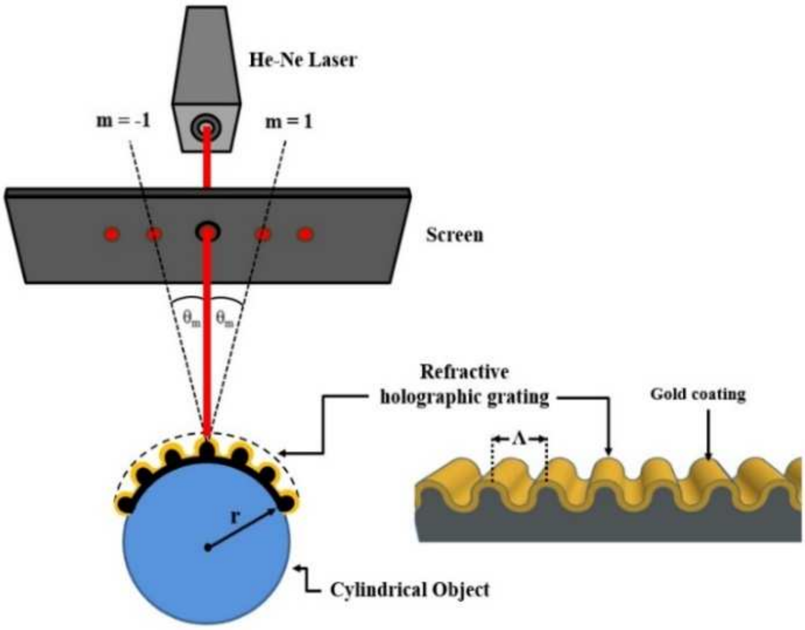

Figure 1. The schematic diagram for measuring the radius of the cylindrical object.

2.2. Experiment method

The experiment setup for measuring the radius of cylindrical objects is shown in figure 1. First, the reflective holographic grating was attached to the various radius of cylindrical object surfaces, where the grating is bent along the cylindrical object surface. The radius of objects are 0.0129 m, 0.0195 m, 0.0260 m, and 0.0319 m. Second, the He-Ne laser with a wavelength of 632.8 nm was used as a light source. By illuminating the laser beam normal to the bent grating surface with a different radius, a diffraction pattern was observed on the screen. Finally, the grating constant is calculated from the observed diffraction pattern. In addition, the grating constant was observed by Scanning Electron Microscope is shown in figure 2. The relationship between the grating constant and the reciprocal radius of the cylindrical objects is shown in figure 3.

3. Results and discussion

3.1. Measurement of grating constant by Scanning Electron Microscope

The grating constant was observed by Scanning Electron Microscope (SEM). Figure 2 shows the image of the reflective holographic grating. The grating constants are shown in table 1.

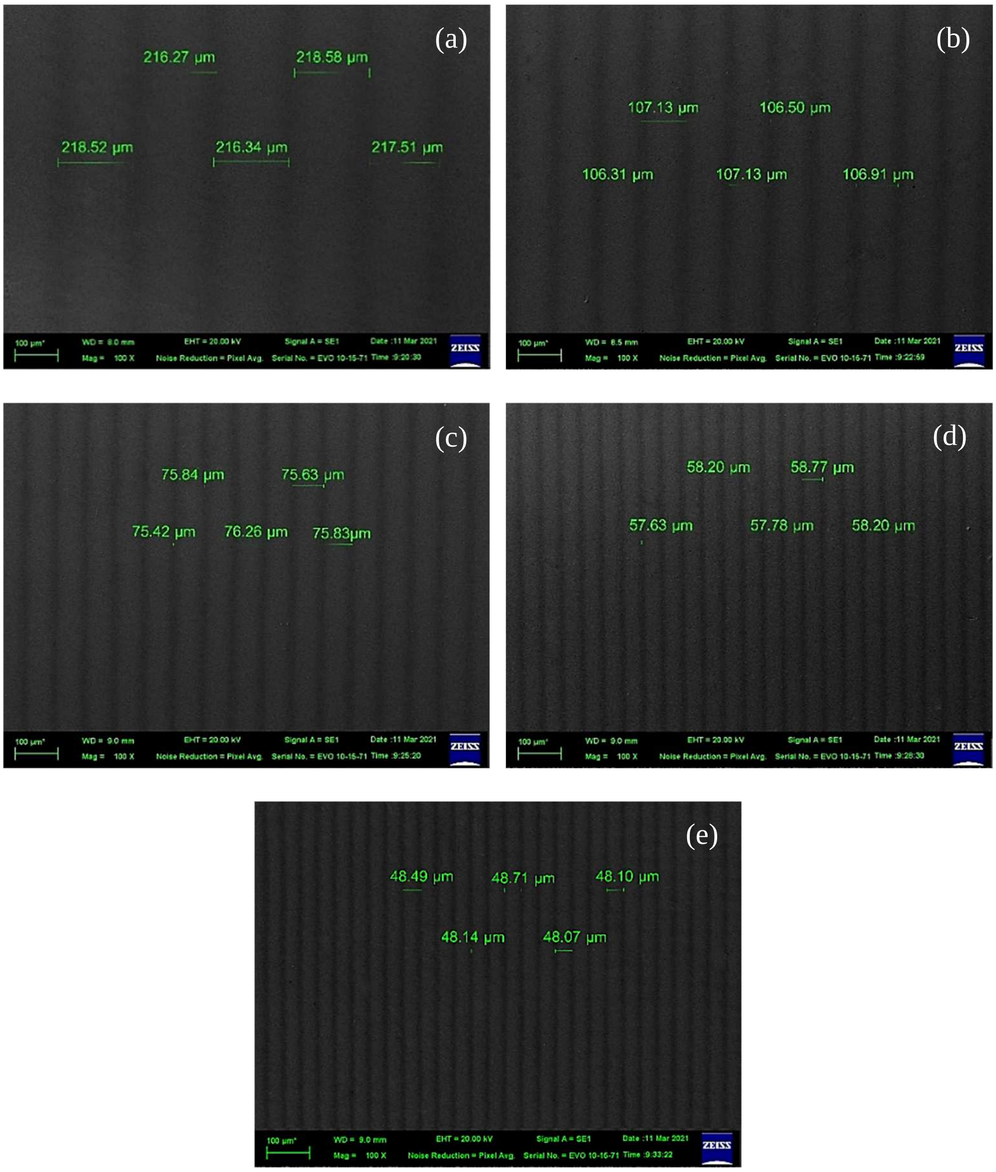

Figure 2. Image of reflective holographic gratings obtained by SEM, where (a) Sample 1, (b) Sample 2, (c) Sample 3, (d) Sample 4, and (e) Sample 5.

3.2. Measurement of grating constant by illumination of the laser beam

The laser beam is normally incident the bent grating surface. The diffraction pattern caused by the bent grating with different radius appears on a screen. The diffraction angle is measured, and the grating constant Λ is calculated from the following equation,

$$\Lambda = \frac{\lambda}{2\sin\theta_m} \tag{1}$$

where λ is the wavelength of the He-Ne laser and θ_m is the angle of the diffraction pattern. The relationship between the grating constant (Λ) and the reciprocal radius of a cylindrical object (1/r) is shown in figure 3. The y-intercept from the graph is shown in table 2.

Table 1. Comparison of the non-bend grating constants, measured by Scanning Electron Microscope (SEM) and measured by illumination of the laser beam.

Method	The grating constants (μm)				
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Measured by SEM	217.44	106.79	75.80	58.12	48.30
Measured by experiment	218.77	100.35	76.11	58.99	47.27
Percentage difference (%)	0.61	6.21	0.41	1.49	2.16

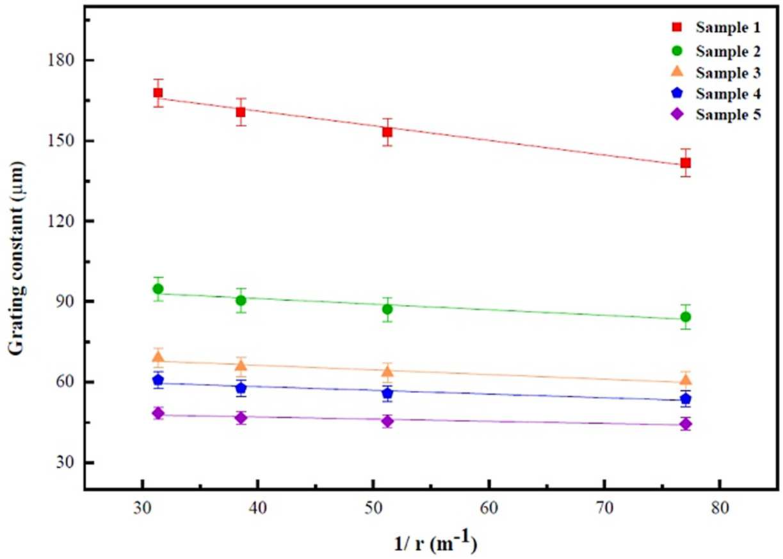

Figure 3. The relationship between the grating constant and the reciprocal radius of the cylindrical objects.

Table 2. The grating constants which measured by the illumination of the laser beam and y-intercept of the graph.

1/r (m^{-1})	The grating constants (μm)				
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
31.37	167.84	94.65	68.98	60.80	48.48
38.54	160.62	90.32	65.67	57.70	46.72
51.23	153.23	87.08	63.41	55.77	45.43
77.04	141.98	84.25	60.41	53.77	44.46
Y-intercept	182.94	99.35	73.16	63.87	50.22
R^2	0.97	0.87	0.91	0.86	0.85

Figure 3 showed that the grating constant and the reciprocal radius of cylindrical objects is a linear relationship. The R-square is in the range of 0.85-0.97. Also, it was found that the y-intercept is consistent with the non-bend grating constant.

4. Conclusion

In this research, we presented the method and experimental results for measuring the radius of cylindrical objects. In the method, the grating is fixed to the surface of a cylindrical object, where the object radius is varied from 0.013 m to 0.032 m. Then the diffraction pattern was observed, and the grating constant of the bent grating of the various radius is calculated. The relationship between the grating constant and the reciprocal radius of the cylindrical object is linear, the R-square is in the range of 0.85 to 0.97, and the y-intercept corresponds to a non-bend grating constant, which is confirmed by two different methods. The non-bend grating constant measured by the illumination of the laser beam is in agreement with that obtained by the SEM imaging. From the experimental results, if the calibration graph between the grating constant and the reciprocal radius has been performed, this system will measure the curvature of an unknown radius, where the object radius is in the range 0.013 - 0.032 m with the error ± 1.02 %. Therefore, we could apply the method to measure the radius of a cylindrical object.

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