Measurement of Angle Encoder Disk Surface Parameters

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Abstract. This research covers a novel approach to non-contact angle encoder disk roughness measurements while using the proposed system attached to the rotary table with an implemented reference angle encoder. Non-contact surface measurement methods are analyzed in the paper. The proposed non-contact surface roughness measurement technique involves the use of a conventional optical disc laser reading system as a cost saving solution. Assets and drawbacks as well as detailed analysis of the measurement procedure are given in the paper. The structure of the device is presented within this article together experimental results.

1. Introduction

Rotary encoders are widely used in precision angle measuring instrumentation to determine the position of the rotation axis. The main component of rotary encoder is a disk with the grating of various pitches which is scanned by a reading head unit. Nonuniformity of the grating and eccentricity of the pattern in combination with geometric parameters of grating lines can cause significant measurement errors. Therefore, it is very useful to analyse the surface of these disks. All surface roughness measurement methods may be classified into contact and non-contact methods. Sometimes the combination of both types is used for measurements [16, 21]. Contact stylus based methods usually have the drawbacks of surface scratching, limited lateral accuracy, longer duration and higher noise level [19]. However, some of methods [2, 14] use generated noise to determine the roughness of the surface. To overcome previously mentioned contact measurement problems, this research focuses on non-contact optical method. The main advantage of optical methods such as profilometry, interferometry, atomic force microscopy, method of optical correlation, microwave [12] and laser speckle is measurement speed [2,8]. To achieve high resolution, the white light interferometry [7] is often used in surface measurement experiments. The optical methods used together with the online measurement techniques are able to ensure roughness measurement in the range of 0.025 µm-1.6 µm. Such methods are more stable in comparison to contact-based stylus methods and minimize the potential for damage [4].Using an interference microscope for surface roughness measurements enables an accuracy of up to 0.02 nm [15]. However, instrumentation for high resolution scanning is expensive [16,20]. In this research, object surface scanning is used also as a measurement technique, i.e. by analysing surface it is possible to determine geometric properties of the encoder disc grating pattern. In order to reduce the cost of instrumentation CD reading heads can be implemented in other measuring systems and applied in fields of accelerometry, profilometry and linear measurements [3, 5, 11]. Therefore, this method was applied in the field of angle encoder disk surface quality measurements as presented further in this paper. The proposed approach suggests a low cost non-contact angle encoder disc surface scanning technique based on a conventional optical disc laser reading head principle.

2. The design of the roughness measuring system

The impact of interferometric measurements on surface quality inspection is undeniable. Especially, in case of measuring small fragments. The use of a laser interferometer allows to measure the desired characteristics of the surface, but unfortunately the price of such instruments is significant, thereby limiting their use [7, 18]. A novel rotary measuring system was designed in order to detect defects of the grating shape as well as to determine unevenness and roughness of the encoder disk and its coating. The grating shape defects can occur due to mechanical damage and dirt. Unevenness of coating thickness is especially relevant in high resolution angle encoder disks because it creates a spatial distortion of a grating width and causes an error in angular position setting. The roughness of a grating surface diminishes the possibility of small defect detection. Determination of the main integral parameter R_a (average of the absolute values) and the mean square deviation value R_q helps to evaluate the roughness of the metalized coating of the encoder disk [13, 17].

2.1. Operating principle

During the measurements the high frequency component could provide us with the information about surface's roughness, scratches or shape and contrast of the grating. Fig. 1 shows the structural scheme of a typical CD laser head unit. The laser beam was diffracted into 3 beams and collimated [3]. The central beam had the highest intensity of 50% light. Intensity of the side beams is 25%.

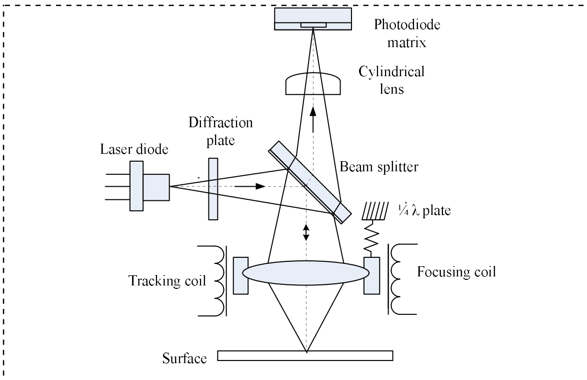

Figure 1. The optical focusing system.

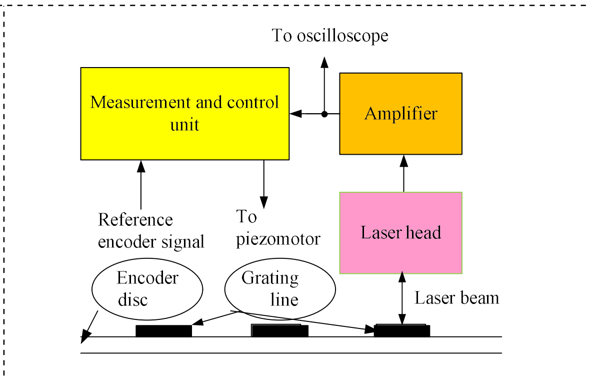

Figure 2. Structure of the measuring system

After crossing ¼ λ plate the beam was directed to the beam splitter and the measured surface, from which reflected with a 180° polarization angle shift. Then the reflected beam passed through the cylindrical lens to the photodiode matrix. The structure of the measurement system is shown in Fig. 2. The amplifier was connected to the conventional CD laser head unit. In this arrangement, the laser head signals were fed to the signal amplifier. The signal used for forming and focusing with the coil control units was obtained from the amplified signal. The scanning component used in the system, had a piezo-ceramic gear in order to diminish the vibration. Measurement and control unit analysed the signal obtained and detects the defects in a grating shape. Surface scanning device was mounted on a precision rotary platform with a piezoelectric actuator and aerostatic suspension. These solutions resulted a smooth rotation and low vibration level. Angular position was monitored using an encoder RON 905, manufactured by Dr. Johannes Heidenhain GmbH [6].

3. Experimental approach and the results

The two step experiment of this research led to the analysis of the results obtained using a low cost optical disc laser head as an approach to obtaining data of surface roughness and unevenness measurement.

3.1. Measurement of calibration plate parameters

Surface scanning was performed using a precision rotary platform with a piezoelectric actuator and aerostatic suspension in order to minimize the influence of vibration. Angular position was monitored using previously mentioned reference angle encoder [1, 6].
As a first step of experiment, two different calibration plates were attached to the rotary platform. Both of them with known thickness which differ from the reference plate by 8±0.4 µm. Relative uncertainty of the calibration plate was 5 %. The difference between obtained realization average values, divided by a known difference in thickness (8 µm), provided a value of the pursued static calibration coefficient (K_{st}) [mV/µm].

$$K_{st} = \frac{\overline{V}_1 - \overline{V}_2}{8} \qquad (1)$$

where $\overline{V}_1$ and $\overline{V}_2$ were arithmetic means of the calibration plate measurement results. For the experiment the broadband data channel is used and the signal are amplified and processed by a simple home made circuit. In

this case it was important to determine the calibration coefficients which described the sensitivity of the measuring system in order to transform the signal voltage fluctuations into the distance displacement.
There were overall 10 000 reference points. An average of the difference in thickness gave the calibration coefficient, K_{st}=40.9 mV/µm. The level of rapid fluctuations (the total noise), was measured during a movement and is 0.0067 µm, illustrating the surface roughness. The internal noise level of the measuring system was determined to be 0.0084 mV. This means that the measurement of features seen in the sample was almost four times larger than the base signal level due to the noise. High frequency component was proportional to the roughness of the plate and the noise level. It can be determined effectively through Allan variance [10] calculation:

$$D_a = \frac{1}{N-1}\sum_{i=1}^{N}(V_i - V_{i-1})^2 \qquad (2)$$

where D_a - high frequency component; N – number of measurements; V_i – i-th measurement value, respectively a total value of the rapid fluctuation signal. During the signal filtering the random error components are significantly suppressed, and the influence of the unevenness depends on the ratio of spatial wavelength λ_t and the length l_{pl}. In the worst case, when the ratio is $\frac{\lambda_t}{l_{pl}} = 2$, the half wavelength fits in the whole length of the plate. Then the random component caused by the unevenness reaches its highest value. As the average roughness amplitude of the reference plate was 1.6 µm, the value of the dynamic calibration coefficient could be found as a ratio of average roughness amplitudes of the measured surface and the reference plate. Since the average roughness amplitude of the measured plate was R_{aMEAS}=0.041 µm, the dynamic calibration coefficient was determined K_{dyn}= 25.6 mV/µm. As well as static calibration coefficient, dynamic calibration coefficient depends on how enhanced the treatment process is. Therefore, they are effective just for a certain realization of the measurement device.

3.2. Measurement of the angle encoder disc parameters

The effect of noise in surface roughness measurement is discussed in publications [9, 14]. The signal of the reference encoder was used to analyse the quality of the grating under test as well as to determine the dynamic parameters of the rotary platform. The surface scanning device includes precision rotary platform with a piezoelectric actuator and aerostatic suspension. A laser scanning head, primary photoreceiver and signal amplifiers were placed on the top of the rotary platform. Fig. 3 shows a real signal of encoder grating with some defects. The first defect clearly indicates the mechanical damage to the grating line (point 163), therefore, this disc must be discarded, the second damage at point 175 indication can be caused by surface impurities. Any rotation speed imbalance can distort the scale and such an imbalance grows significantly when the platform rotation speed is reduced. Figure 4 shows signals of reference encoder and disk under test.

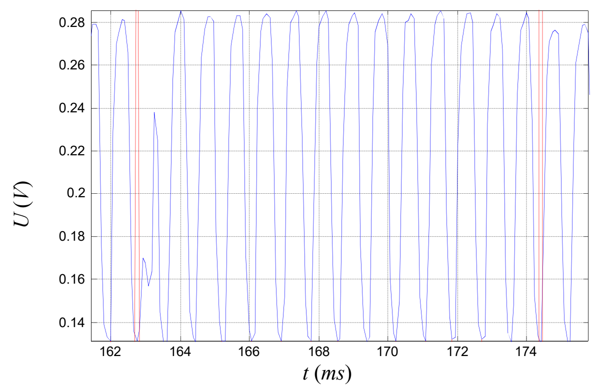

Figure 3. Signal of the disk grating with defects

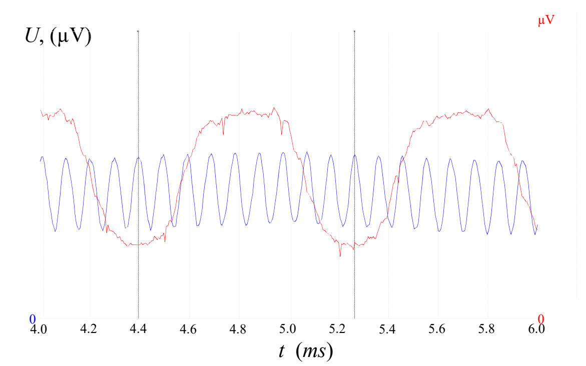

Figure 4. The signals of both reference encoder and a disk under test (lower frequency).

4. Conclusions

The research undertaken has revealed that it is possible to perform an effective surface roughness evaluation using the optical disc laser reading head. The advantage of such a device is that it can be used during the angle encoder disk manufacturing process for quality control as well as for the surface parameter and imperfection analysis of other measured objects as the approach offers a rapid, often preliminary, evaluation where this is required. The laser measuring system might also be used for surface coating structure analysis which is hardly possible to achieve by using other instrumentation. To demonstrate the efficacy of the device, a calibration procedure has been described and the results of roughness measurements using the proposed setup are presented in paper. Using proposed approach the surface roughness can be measured within the range of 0.5-1.0 μm. One of the main advantages of the proposed setup is that the roughness of the surface can be measured at the same time as angular position of the disk grating because of the reference angle encoder implemented into the measuring system.

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