Inspection Method for Roller Parts Using Phase-Shift-Moiré 3D Measurement Method

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Abstract

A high speed and high-resolution inspection method for shallow defects (waviness) on roller parts is proposed, using 3D phase-shift-moiré technique which is based on the geometrical characteristics of cylindrical shape of roller parts. The experimental test bed shows that the proposed method can measure the shape of the waviness around 2μm deep and reduce the measuring time less than 1/3 that of the conventional shift method. The proposed method makes it possible to introduce full-automated inspection system.

Introduction

Copiers, printers, facsimiles and other office machines contain various roller parts, such as photoconductor drums, developing rollers and fixing rollers. Since surface conditions of these roller parts directly influence final image quality, these parts must be inspected strictly. Furthermore, in terms of environmental concern the reuse of these parts becomes important, which requires an efficient inspection method. So far these roller parts have been inspected by human, which leads to various problems, for instance dispersion of judgement, adequate training is needed, and inspectors are hard to find et al.. Consequently, the introduction of full-automated inspection system is of urgent necessity and some automated examples exist.[1]

Generally in those examples, a line sensor camera acquires the surface image of the roller part, then defects are detected using image processing technique. Since these methods mainly make use of light scattering caused by defects, detection sensitivity is high against defects with significant shape changes such as flaws and foreign substance adhesion. However, it is difficult to detect shallow defects (waviness) such as those shown in Figure 1, because irradiation light is not scattered.

Since the influence of waviness on image quality differs depending on depth, it is ideal to judge these defects against depth. However, those inspection examples can not measure the depth of these defects. In addition high speed measuring method is needed in order to accomplish measuring time required for inspection process. The targeted value of height resolution is 1μm, and that of measuring time is 10 seconds (φ 30 x 340mm).

Recently several 3Dmeasuring methods have been developed which have potential to measure the depth of these defects. Figure 2[2,3] shows the estimation of measuring time and height resolution of 3D measuring methods assuming a sampling area of φ30 x 340 mm at intervals of 0.1 mm by 1 measuring head. However, none of the established measuring methods could achieve the required performance.

Phase-shift moiré method is one of the promising approach and has been used successfully for flat parts such as liquid crystal panels.[4] However, when it is applied for roller parts, it requires rather long measuring time because mechanical movement to shift the phase and image acquiring of moiré fringe must be repeated.[4,5]

This paper proposes high speed and high resolution measuring method for roller parts using phase-shift-moiré method. Particularly the method to reduce measuring time is proposed which is based on the geometric characteristics of roller parts.

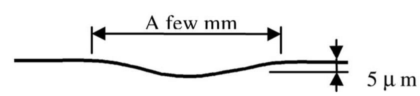

Figure 1. A shallow defect (waviness)

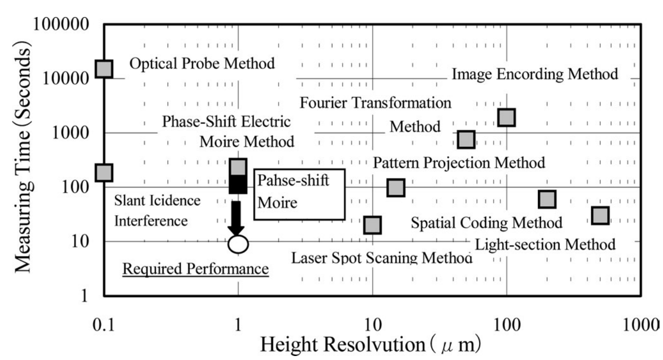

Figure 2. Comparison of 3D measuring methods

Moiré Topography

This section explains moiré 3D measuring method.[6] The optical component of shadow moiré topography is shown in Figure 3. Points where the ray from light source S (solid line) through the bright part (opening) of grating G and the observation line from CCD camera (dotted line) through the same bright part cross can be observed. Then contour line is formed on the line which linked these crossing points. The shadow of the grating G is projected on the object by the light source S. Then it is deformed corresponding to the surface shape of the object, and observing the deformed shadow through the same grating G, moiré fringes (contour line) are formed. Moiré fringes intensity I (h) at a distance h from the grating G can be shown by formula (1). Here, d is the distance between the light source S and the center of camera lens; l is the distance from the light source S to the lattice reference plane and p is the pitch of the grating G.

$$I(h) = \cos\left(\frac{2\pi}{p}\frac{dh}{h+1}\right) \tag{1}$$

On the moiré fringes, we put the number of the order from the lattice surface as a reference plane (No.0), then to the first, second and so on. Then, when the distance of the moiré fringe in the order of n from the lattice surface is made h_n, formula (2) is created by substituting formula (1) by cos2πn.

$$h_n = \frac{npl}{d - np} \tag{2}$$

Though interval Δh of the contour line is not constant, assuming d >> np, it can be regarded as Δh = pl/d. In the measurement here, they are p = 83.3 µm, l = 150 mm, d = 290 mm and Δh = 43 µm. An example of the moiré fringes on the developing roller captured by the CCD camera is shown in Figure 4.

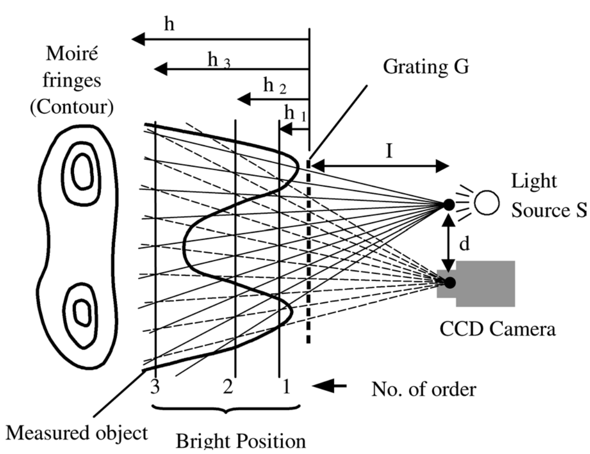

Figure 3. Moiré topography

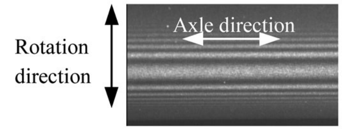

Figure 4. Moiré fringe image on roller part

Phase Shifting Technique

The moiré 3D measuring method has the advantage that the shape can be recognized intuitively by indication of a contour line. The height resolution, however, is a maximum of around 10 µm, so it does not fulfill our target. There is also the problem that concave and convex cannot be differentiated and information on surfaces between the moiré fringes cannot been obtained. These shortcomings can be improved by introducing phase-shift method, which is widely applied to optical interference measurements.

Figure 5 and 6 show how to shift the phase. Three moiré fringe images must be acquired by shifting the phase in a certain quantity ϕ_0 (= nπ/2rad) each time (Figure 5). Focusing on pixel Q (in Figure 5) in the moiré fringe images, the intensity of Q changes as shown in Figure 6 every time it is captured by the camera. When the intensity of pixel Q at the first, second and third captures are named I_1 (Q), I_2 (Q) and I_3 (Q), the initial phase φ (Q), i.e., the phase of the pixel Q of the first captured image, can be found by formula (3). Further, the phases calculated by formula (3) are folded in the range of 0 to 2π(rad) and become discontinuous. Then it is necessary to connect the phase based on a reference point. The height corresponding to phase 2π can be calculated as contour line interval Δh = sl/d, as described above. Therefore, if phase φ (Q) on pixel point Q found by formula (3) is converted into the height, shape data can be obtained. Height resolution less than 1/30 of the contour line interval Δh can be obtained by this technique. In the measurement here Δh = 43 µm, then height resolution is around 1 µm.

$$\phi(Q) = \tan^{-1}\left(\frac{I_0 - I_1}{I_2 - I_1}\right) + \frac{\pi}{4} \tag{3}$$

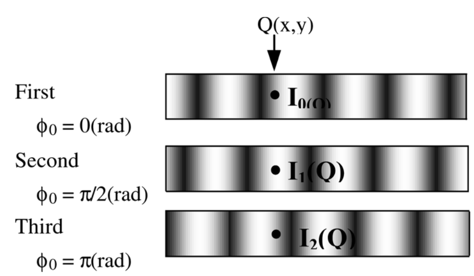

Figure 5. Shifting a phase

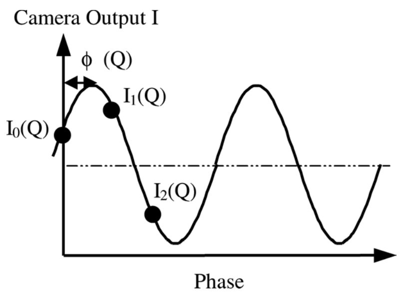

Figure 6. Shifting a phase

Fast Phase Shifting Method for Roller Parts

In order to shift the phase of moiré fringe it is necessary to move the position of the grating or the roller part or the light source and so on. Applying it for the roller part, the part must be rotated more than three times, because mechanical movement to shift the phase and image acquiring of moiré fringe must be repeated.[2,3] In result it requires rather long measuring time, then general shifting method can not be applied for roller parts inspection.

With our technique, several (more than 3) sensors (for example, any three lines on a camera) are used. Interval of moiré fringe phase acquired by each sensor must be adjusted to become $\pi/4$rad. This technique uses the geometrical characteristics of cylindrical shape of the roller part (Figure 7). Focusing on sphere 3, fringe intensity of I_1 (sphere 3) from formula (3) at time t_1 by sensor A, fringe intensity I_0 (sphere 3) at time t_2 by sensor B and, ultimately, at time t_3, fringe intensity I_2 (sphere 3) by sensor C (Table 1) are acquired. Magnification of the optical system and the scanning frequency of the sensor and rotational speed of the roller part are pre-adjusted so that the interval of each observation point of sensors A, B and C on the roller part become $\Delta h/4$ (converted to phase $\pi/4$). Fringe intensity I_0, I_1 and I_2 are substituted in formula (3) and phase φ of sphere 3 is calculated. This phase φ is converted into the shape data using Δh corresponding to phase 2π.

Introducing this phase-shift method eliminates the need for mechanical movement to shift the phase of moiré fringes; the phase-shift becomes possible with just a single rotation of the roller part. As a result, measuring time can be reduced to less than 1/3 that of the conventional method. A high-speed camera can be used for the sensor, but color line sensor is more effective both in cost and measurement speed.

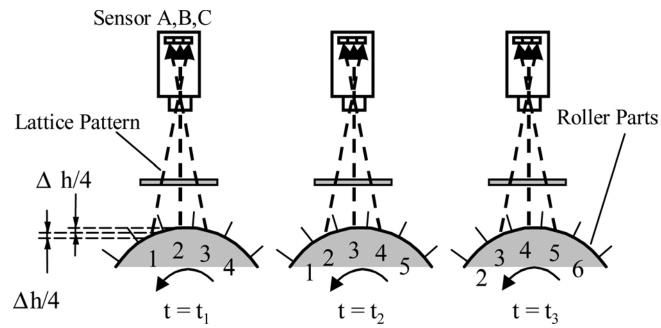

Figure 7. Phase-shift on the roller part

Table 1. Phase Shift Time Sequence

	A-I_1	B-I_0	C-I_2
t_1	Sphere 3	Sphere 2	Sphere 1
t_2	Sphere 4	Sphere 3	Sphere 2
t_3	Sphere 5	Sphere 4	Sphere 3

Measurement Result by the Phase-Shift-Moire Method

Figure 8 shows the equipment component used for the measurement experiment. Parameters are s= 83.3 µm, l = 150 mm, d = 290mm and Δh =43 µm as described above. Ronchi ruling of 50mm wide was used as the grating, and a Sony XC-HR300 CCD camera was used for the camera at a capture rate of 50 frames per second. Focal distance of the lens was 25mm, the field of view was 28 x 28 mm, and resolution of the image was 36 µm/pixel.

Figure 9 shows an example of measuring waviness on a developing roller. X shows the axle direction of the roller part, Y the rotation direction and Z the depth (µm). The range of X:21.6 mm x Y:2.5 mm x Z:16 µm in three dimensions is expressed. Figure 10 shows a section profile in the X direction at Y = 30 (pixel). Measurement of a photoconductor drum is shown in Figures 11 and 12 in the same way.

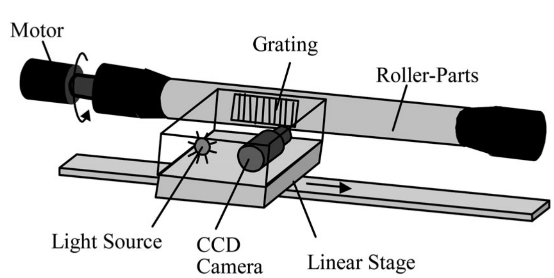

Figure 8. Experiment device

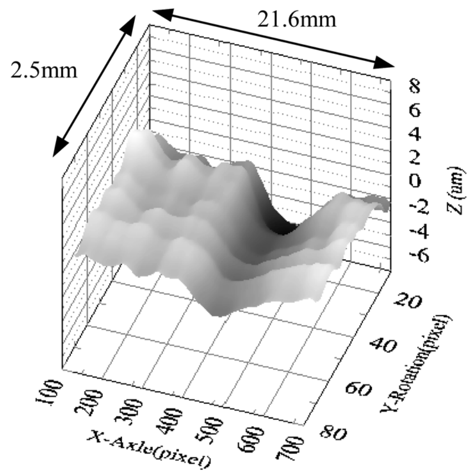

Figure 9. Measurement result (developing roller)

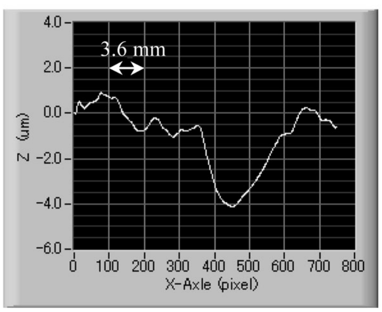

Figure 10. X (axle) direction profile (Y=30 pixel)

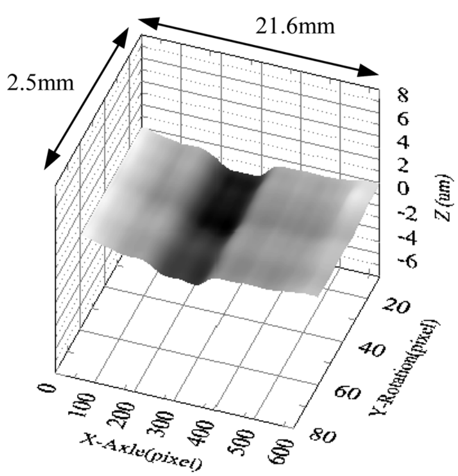

Figure 11. Measurement result (photoconductor drum)

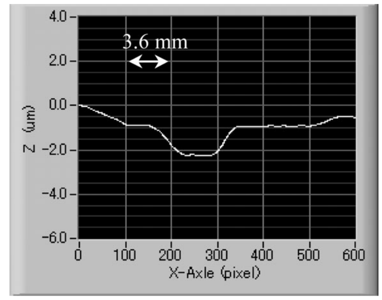

Figure 12. X (axle) direction profile (Y = 30 pixel)

Measurement Results of Axle Direction Profile by Stylus-type Measurement Machine

Figure 13 shows the X(axle) direction profile of the developing roller shown in Figures 9 and 10, measured by the stylus-type shape measurement machine. It shows defects of around 10mm wide and around 5 µm deep, and the measurement result is the same level as the result in Figure 10 obtained by the phase-shift moiré method.

Figure 14 shows the X(axle) direction profile of the photoconductor drum shown in Figures 11 and 12, measured in the same way. Here again the defect of around 6mm wide and 1.5 µm deep is about the same as the measurement result in Figure 12 obtained by the phase-shift moiré method. With these results, proposed method is confirmed to be able to measure the shape of shallow defects (waviness) around 2 µm deep.

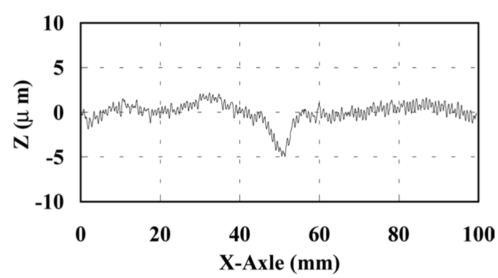

Figure 13. Section profile (developing roller) by a stylus-type machine

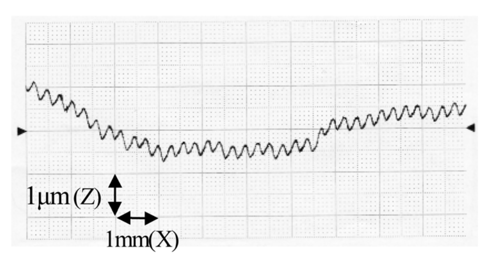

Figure 14. Section profile (photoconductor drum) by a stylus-type machine

Conclusion

A high speed and high resolution inspection method is proposed for roller parts which uses phase-shift moiré 3D measuring method based on the geometrical characteristics of roller parts. The measuring time is reduced to less than 1/3 that of the conventional shift method. The experimental test bed shows that the proposed method can measure the shape of shallow defects (waviness) around 2 µm deep. The proposed method makes it possible to introduce full-automated inspection system.

References

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Biography

Ryuji Sakita graduated from the industrial engineering department of Yokohama National University, Japan in 1990 and entered Ricoh Company, LTD. He belongs to Research and Development Group, where he has engaged in research of high resolution 3D measuring method and developed automatic inspection system for photoconductor drums. His major field of specialty is optical measurement.