Surface texture characterization of ultra-precision machined parts based on laser speckle pattern analysis

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Abstract

Demands for estimating the surface texture of machined parts have recently increased in a variety of industries. This paper presents a practical method for characterizing the surface texture of ultra-precision machined surfaces by analysing laser speckle patterns. By observing the laser speckle patterns formed by various machined surface, the relationship between the surface texture and the laser speckle pattern can be classified. In addition, the laser speckle patterns were evaluated with some characteristic parameters. The proposed characteristic parameters are effective for evaluating the surface texture.

1 Introduction

Surface texture of ultra-precision machined parts provide the surface function such as friction, wear resistance, corrosion, fatigue, and wetting [1]. Therefore, accurate and effective measuring methods of surface texture have been required in various industrial sectors. Laser speckle method is an effective means for meeting such requirements, so that laser speckles have been widely investigated for measuring surface roughness, i.e., a speckle contrast technique, an angular speckle correlation technique, a polychromatic speckle correlation technique. These conventional techniques, however, focused on a single parameter extracted from laser speckle pattern, so that other useful information included in laser speckle pattern was not effectively utilized. This paper describes the relationship between surface texture and laser speckle pattern, and then proposes fundamental characteristic parameters obtained from laser speckle. Furthermore, the proposed parameters characterize the surface texture of ultra-precision machined surface.

2 Laser speckle observation instrument

Figure 1 shows the optical system of a developed laser speckle observation instrument. The instrument consists of a laser source (λ=635nm), a CCD camera, an indexing stage with an objective machined part, a pinhole, and some optical lenses. In order to evaluate the laser speckle pattern by the incidence angle of laser beam, the instrument could irradiate laser beam to the objective surface from various angles by rotating the stage. Laser speckle patterns were formed on the CCD camera placed on the specular reflection angle through the convex lens D. The CCD camera and the convex lens D were fixed at a distance of the focal length of the lens D.

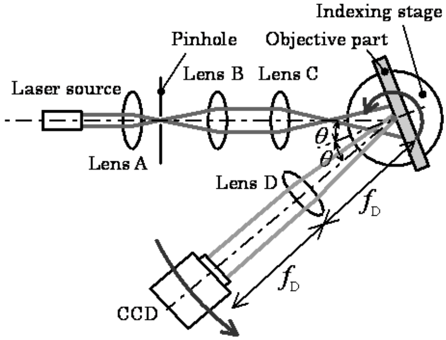

Figure 1: Laser speckle observation instrument

3 Relationship between surface texture and laser speckle pattern

Laser speckle patterns varied with the types of machined surfaces, such as lapped surfaces, ground surfaces, and milled surfaces. Observation results confirmed that the laser speckle patterns can be characterized by the characteristic of the surface structure, as shown in Fig.2. An aperiodic structure on a lapped surface projected a mottled speckle pattern to the CCD camera. On the other hands, the laser speckle pattern formed by a periodic structure on a ground surface showed a banded pattern, which was in the same direction as tool marks. The rougher periodic structure caused more vivid banded patterns. In the case of milled surface, with the very periodic tool marks, very similar pattern run parallel in the laser speckle pattern. In general, the actual machined surfaces had both the periodic and the aperiodic structures, so that the laser speckle were mixture of mottled and banded patterns. In such a case, the laser speckle patterns became fibrous or scaly. In the case that the surface profile was much rougher than the wavelength of the laser beam, the intensity difference between the bright part and the dark part was developed, so that the laser speckle pattern became spotted pattern. In consequence, the laser speckle pattern provided valuable information related to the surface texture, i.e. the tool mark direction, the periodicity of the tool marks, and the roughness of the surface profile. Therefore, characteristic parameters of the surface texture could be evaluated by analyzing the laser speckle pattern.

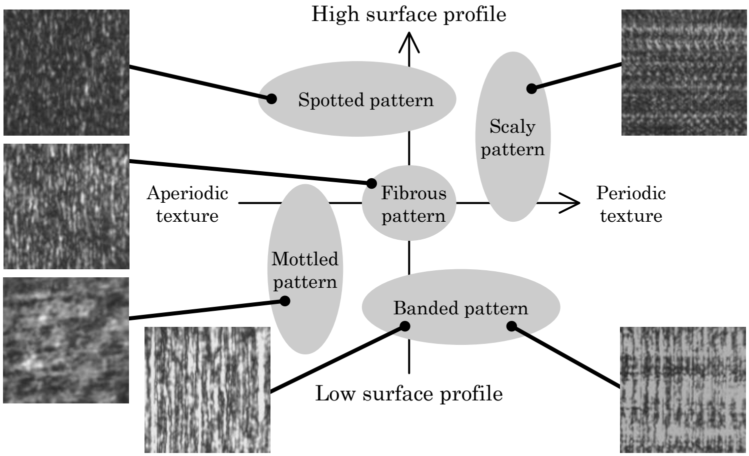

Figure 2: Classification of laser speckle patterns

4 Characteristic parameters of laser speckle pattern

The laser speckle patterns formed by lapped surfaces, ground surfaces, and milled surfaces were evaluated with plural characteristic parameters. Fig.3 shows the relationship between the mean value of speckle intensity in one line and the mean height of profile elements of the assessed profile (Rc) defined in the ISO4287-1997. The X and Y-directions indicate the tool mark direction and the perpendicular direction against tool mark, respectively. The speckle intensity decreased linearly in the range that Rc was less than 400nm. The measured data of all the machined surfaces in both the directions were on the same line regardless of the laser incidence angle. Therefore, the Rc of the machined surface could be estimated with the mean value of observed speckle intensity.

Figure 4 shows the relationship between the autocorrelation length of the speckle intensity distribution in one line and the mean width of profile elements of the assessed profile (RSm) defined in the ISO4287-1997. Except for lapped and ground surfaces in X-direction, the autocorrelation length apparently decreased in the range that RSm was larger than 55μm. RSm less than 55μm could not be evaluated with the laser speckle because the maximum value of autocorrelation length was 940μm, which was limited by the size of observed area. In the X-direction of lapped or ground surface, the autocorrelation length was unclear due to low periodicity of surface profile. Consequently, the RSm in the perpendicular direction against tool marks could be estimated with the correlation length of the autocorrelation function.

As stated above, the Rc in any direction and the RSm in the perpendicular direction against tool marks could be estimated with the mean value and the autocorrelation length of the speckle intensity distribution in one line.

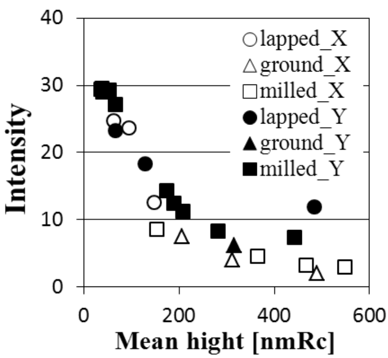

Figure 3: Relationship between speckle intensity and Rc

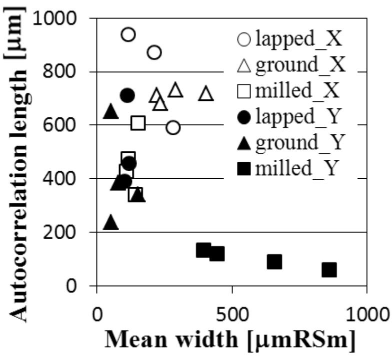

Figure 4: Relationship between correlation length and RSm

5 Conclusions

Experimental results confirmed that the laser speckle patterns includes various information on the surface texture, and that surface texture can be evaluated by using with the characteristics parameters of the laser speckle proposed.

References:

[1] N. Moronuki, D. Kajita and A. Kaneko, Micro-structure design of the floor to prevent slip, Proceedings of the 7th euspen International Conference, pp.513-516, 2007.