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Study on contact performance of ultrasonic-assisted grinding surface

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ABSTRACT

The contact performance of ultrasonic-assisted grinding surface is studied in this paper. An improved simplified model of rough surface profile is proposed to find the microscopic feature parameters, such as the curvature radius of the asperity, which are suitable for contact analysis and calculation. Then a more accurate rough surface contact analysis model is obtained by combining the classical ZMC contact model. Based on the contact analysis model, the contact mechanism of ultrasonic-assisted grinding surface is studied. The contact stiffness and local maximum contact pressure of the surfaces under different cutting depths and ultrasonic amplitudes are calculated, and the correlation rule between the parameters of ultrasonic-assisted grinding and the contact performance of the machined surface is obtained: (1) With the increase of the cutting depth, the surface roughness of the workpiece increases; under the same load, the contact stiffness decreases and the maximum local contact pressure increases. (2) With the increase of the ultrasonic amplitude, the surface roughness of the workpiece first decreases and then increases. Under the same load, the contact stiffness increases first and then decreases, while the maximum local contact pressure resents an opposite variation trend. Under the experimental conditions, the surface contact performance of the workpiece is the best when the ultrasonic amplitude is 4 μm. Additionally, the contact performance of the ultrasonic-assisted grinding surface and the conventional grinding surface is compared: (1) When the ultrasonic amplitude is 4 μm, the surface roughness of the workpiece is at least 24% lower than that of the conventional grinding surface. (2) Under the same load, the surface contact stiffness of the ultrasonic-assisted grinding surface is increased by at least 68%, and the maximum local contact pressure is reduced by at least 17%. It is found that the interference motion of abrasive particles in the ultrasonic-assisted grinding process makes the surface height distribution more concentrated and the density of asperity increased, which results in a better contact performance compared with the conventional grinding surface.

1. Introduction

The surfaces of mechanical parts are uneven at the micro level, characterized by a series of discretely distributed contact areas, and the real contact area which is only part of the smooth nominal contact area is far smaller than the nominal contact area. The real contact area and the contact pressure of the contact surface directly affect the bearing capacity, friction, wear, fatigue and other properties of the transmission parts [1–4]. For example, the existence of rough surface decreases the local stiffness of a mechanical structure, which directly affects the static and dynamic characteristics of the structure, and meanwhile increases the local contact pressure, which directly affects the fatigue life.

Ultrasonic-assisted grinding is a grinding process formed by applying ultrasonic vibration during the traditional grinding process. In ultrasonic-assisted grinding, the effects of micro differentiation, rigidity, cutting edge sharpening, cavitation, and stress and energy concentration will be produced [5], which can decrease the grinding force [6] and grinding temperature [7], reduce wheel blockage and wheel wear and improve the integrity of the machined surface [8]. Therefore, ultrasonic-assisted grinding has always been a hot spot of research.

The workpiece with ultrasonic-assisted grinding has different surface features from the conventional grinding workpiece. Xue [9] studied the ultrasonic-assisted grinding of high performance alloy with the electroplated grinding wheel. It was found that under certain conditions, the mesh microstructure appeared on the surface of ultrasonic-assisted grinding and that the mesh microstructure showed different characteristics under different processing parameters. It was observed by Chen [10] that the increase of ultrasonic amplitude decreased the lateral bulge of the mesh microstructure, increased the interference

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degree of adjacent grains, and decreased the surface roughness. In recent years, researchers have focused mainly on the relationship between parameters of ultrasonic-assisted grinding and surface roughness of workpiece [11–13]. However, the actual contact performance of ultrasonic-assisted grinding surfaces under the micro morphology has not been deeply investigated.

In order to study the contact performance of mechanical parts under micromorphology more accurately and intensively, the rough surface contact model based on statistics theory has been widely studied. Greenwood and Williamson [14] first proposed a rough plane contact model considering the elastic deformation of the asperity (the GW model), but the GW model is limited to the assumption of pure elastic deformation. Zhao et al. [15] used the method of interpolation to establish a surface contact model (ZMC model) which considers all the three states: the fully elastic deformation, elastic-plastic deformation and fully plastic deformation. With constant revisions and improvements, the contact model of rough surfaces based on statistics has been widely used in rough surface contact analysis. The height distribution, curvature radius and density of the asperity become the main modeling parameters. However, studies by Whitehouse and Archard [16] have found that the curvature radius and density of asperity calculated by the stochastic process theory cannot represent the intrinsic property of the surface, but depend on the sampling interval. Greenwood [17] proposed that the original definition method of asperity peak cannot reasonably describe the surface asperity, especially when the sampling interval is very small. In the analysis of contact between the actual machined rough surfaces, considering that the surface morphology measured by the optical instrument is affected by the sampling interval [18], the average curvature radius of the asperity calculated by the classical three-point method is usually too small so that it is not suitable for calculation of rough surface contact model.

It can be found from the analysis of existing researches that the following problems need to be studied further: (1) the relationship between the surface micromorphology of the workpiece of the ultrasonic-assisted grinding and the contact performance; (2) the relationship between the parameters of ultrasonic-assisted grinding and the contact performance of the machined surface; (3) comparison of contact performance between surfaces of ultrasonic-assisted grinding and surfaces of conventional grinding. An improved simplified model of rough surface profile is proposed in this paper and the measured micromorphology data of ultrasonic-assisted grinding surface is simplified to find the microscopic feature parameters, such as the curvature radius of the asperity, which are suitable for contact analysis and calculation. The contact stiffness and local maximum contact pressure of the surfaces under different cutting depths and ultrasonic amplitudes are calculated by combining the classical ZMC contact model, and the correlation rule between the parameters of ultrasonic-assisted grinding and the contact performance of the machined surface is obtained. The contact performance of the ultrasonic-assisted grinding surface and the conventional grinding surface is compared, and the mechanism of improvement on contact performance of ultrasonic-assisted grinding surface is studied.

2. Improved simplified model of micro surface profile

To solve the contact problem of rough surfaces, statistical models have been modified and improved. So far, these models have been widely used in rough surface contact analysis. However, important modeling parameters, such as the curvature radius and density of asperity, cannot be directly measured by measuring instruments. Usually, researchers adopt the 3-point method to define the asperity peaks and calculate the radius of curvature and the density of asperity. Considering that the surface morphology measured by the optical instrument is affected by the sampling interval, the average curvature radius of the asperity calculated by the classical three-point method is usually too small and is influenced by the sampling interval so that it is not suitable for calculation of rough surface contact model. Based on the literature [19], a new method of asperity definition based on the reference line and the height of peak and valley is proposed in this paper. The real profile of the rough surface is described by parabolas and they are simulated by ensuring the minimum least square error between the parabolas and the real profile. The surface profile of the workpiece is measured by the optical profilometer, and the discrete points of the surface profile of the workpiece are obtained. Considering the groove characteristics of the grinding surface, the two-dimensional profile in the vertical groove direction is simplified by parabolas, so as to facilitate further contact analysis of the surface of the ultrasonic-assisted grinding.

2.1. Definition method of asperity

Using tools such as a white light interferometer, the discrete point height sequence of the profile of rough surface $z(i)$ is obtained. The average height line of the surface h_0 is calculated, and it is taken as the reference line.

$$h_0 = (1/N) \sum_{i=1}^{N} z_i \tag{1}$$

In the equation, N is the total number of the discrete points of the surface profile.

According to the relationship between the measured profile and the reference line, the continuous discrete points which are higher than the reference line are regarded as a same asperity, and the discrete points of the profile are simplified by a parabola. The simplified sketch of the parabolic asperity is shown in Fig. 1.

As indicated by the new problem found by Kucharski et al. [20], the location of the reference line will have a huge impact on the simplified results in the method mentioned above. As shown in Fig. 2, the discrete points in the figure are all higher than the reference line. If the discrete points are divided by the reference line only, they will be defined as one asperity for simplification. However, it is obvious that, in the case shown in the figure, the simplification error will be smaller if the discrete points are divided into two asperities.

In the rough surface profile, peak points and valley points are important features which can be determined easily. Therefore, the division method is discussed by considering the ratio between the height of the valley point and the height of the peak point. The results show that when the ratio between the height of the valley point and the height of the peak point is less than 0.5, the simplification error of dividing into two asperities is invariably lower than the simplification error of dividing into one asperity. Therefore, in order to reduce the simplification error and simplify the rough surface profile more accurately, on the

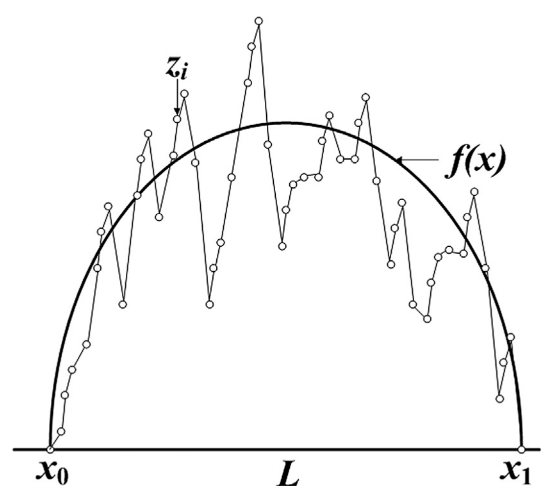

Fig. 1. Simplified sketch of parabolic asperity.