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Effect analysis of the resolution of non-ideal surface models for mechanical contact simulations

Akimasa Otsuka[1] and Fusaomi Nagata[1]

1 Department of Mechanical Engineering, Sanyo-Onoda City University, 1-1-1 Daigaku-Dori., Sanyo-Onoda, Yamaguchi, 756-0884, Japan

Corresponding Author / Email: otsuka_a@rs.socu.ac.jp, TEL: +81-836-88-4548, FAX: +81-836-88-3400

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CAD and CAE are indispensable tools for the design and development of mechanical products. Especially in the field of tolerance analysis, researchers have studied a model with unevenness actively since around 2010. These studies are mainly divided into research on how to create unevenness models and research on how to apply unevenness models. The model is defined as a non-ideal model in ISO 17450 and represents the models by a set of points or mesh called skin model shapes. When applying the non-ideal model to an actual product, the resolution of the surface models affects the calculation time and accuracy. For example, to obtain highly accurate results in contact analysis, it is necessary to rotate small changes in posture for each step. The repetition numbers in loops in the calculation program increase and calculation time also proportionally increase if the number of the points of the surfaces is large. Therefore, the suitable resolution of the surface models should be set. In this study, several resolution conditions for the non-ideal model are prepared to compare the calculation results. The Monte-Carlo simulations of contact analysis are performed using the non-ideal model pair of each resolution condition. The Monte-Carlo simulations are performed 100 times for each resolution condition, such as the square of 21, 42, 63, 84, and 105, to investigate the distribution of rotation angles.

1. Introduction

CAD and CAE are indispensable tools for the design and development of mechanical products. Ideal features, which are features defined by a parametrized equation, are used in the tools as the product shapes. However, machining errors are inevitable in machining, and the machined parts have various irregularities. For this reason, there is a difference in performance between products using the ideal shape and those manufactured shapes. This is a shape or feature modeling error, and it is becoming necessary to reduce the difference to improve various calculation accuracy. Especially in the field of tolerance analysis, researchers have studied a model with unevenness actively since around 2010. These studies are mainly divided into research on how to create unevenness models and research on how to apply unevenness models. In the later research, in particular, assembly analysis and backlash analysis using a component model with unevenness are mainly performed.

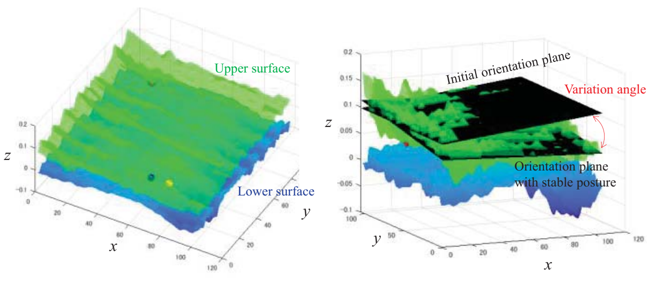
By the way, this unevenness model is called a non-ideal model in ISO 17450. To use it practically, the model defined by a set of points or mesh is called skin model shapes. When applying the non-ideal model to an actual product, the resolution of the surface models affects the calculation time and accuracy. For example, to obtain highly accurate results in contact analysis, it is necessary to rotate small changes in posture for each step. The repetition numbers in loops in the calculation program increase and calculation time also proportionally increase if the number of the points of the surfaces is large. Therefore, the suitable resolution of the surface models should be set.

In this study, several resolution conditions for the non-ideal model are prepared to compare the calculation results. The Monte-Carlo simulations of contact analysis are performed using the non-ideal model pair of each resolution condition. The distribution of the final posture of the surfaces in the contact state is analyzed. The procedure of the study is shown as follows. First, a non-ideal surface model is randomly prepared as two contacting planar objects. It is assumed that the surfaces are rigid and do not deform. The posture in which the two surfaces are stable is calculated using contact judgment. The posture variation from the initial posture is expressed by two rotation angles. Because the variable values are important factors in tolerance design, we analyzed the values and computation time. The Monte-Carlo simulations are performed 100 times for each resolution condition, such as the square of 21, 42, 63, 84, and 105, to investigate the distribution of rotation angles. As the resolution increases, the distribution of rotation angles is tended to be zero.

2. Contact simulation

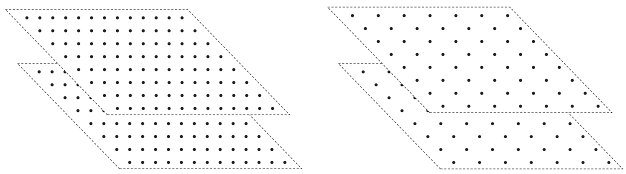
2.1 Overview of contact simulation

The actual surface models machined by a milling machine usually have tool pass marks along to tool movement as shown in Fig.1 (a). The figure also shows examples of the non-ideal surface models created by manufacturing errors using the generation developed by authors [6]. The surface models have periodic cutter marks and are represented by point could data. When the upper and lower mating surfaces contact and if the lower surface is fixed, the orientation of the upper surface changes as shown in Fig. 1 (b). In this study, parts assemble simulation is supposed, and the variation angle is important to evaluate the assembling error of mating parts. Therefore, the variation angle is evaluated in this study. If the density of the point cloud data of the surface is large, the calculation cost will be much higher. The resolution of the non-ideal surface model is an important parameter in the simulation.



(a) (b)

Fig. 1 Contact simulation between two surfaces: (a) Example of two surfaces and contact points in a simulation, (b) Example of variation angle of the upper surface from its initial position.



(a) Example of dense model (b) Example of sparse model

Fig. 2 Resolution of the non-ideal surface model may affect the results of the contact simulations.

2.2 Simulation conditions

The contact simulation software is also developed by the authors. The Monte-Carlo simulations are performed 100 times for each resolution condition, such as the square of 21, 42, 63, 84, and 105, to compare the distribution of rotation angles. A non-ideal plane usually has random unevenness, so the locations of the contact points are also random. The size and spatial frequency of the cutter marks of each simulation are almost the same as shown in Fig. 1. As the conditions of the simulation, the contact surfaces are assumed to be square, and we can change the resolution of the surface. The number of resolution *N*, which is the number of points of the square side, is set to the square of 21, 42, 63, 84, and 105, to investigate the distribution. In the contact simulation, the surface is assumed to be rigid, and the surfaces do not deform at all.

2.3. Result and Discussion

Figure 3 shows histograms of variations of rotation angle *x* and *y* axis respectively. The result of N = 105 is omitted in this figure because the result is similar to the results of N = 84. The variance of the rotation angels around the *x*-axis is larger than the ones of the *y*-axis. The results show that the rotation angle variation around the x-axis tends to increase due to cutter marks. Figure 4 shows the total rotation angle, which is defined as the root sum of the square of the *x* and the *y* rotation angles. These results shows that histograms of N = 64, N = 84 and N = 105, are similar. In other words, N=64 is enough resolution for the periodic surfaces as shown in Fig. 1. If the surface characters such as size and spatial frequency of the cutter mark change, the optimal resolution number will also change.

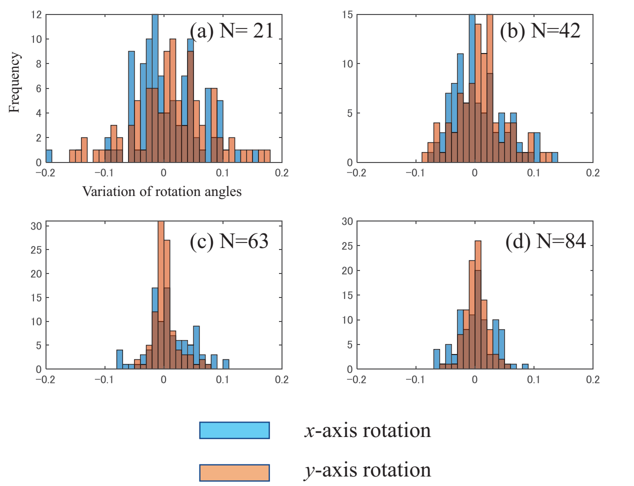


Fig. 3 Histograms of respective rotation angles around the *x*-axis and the *y*-axis.

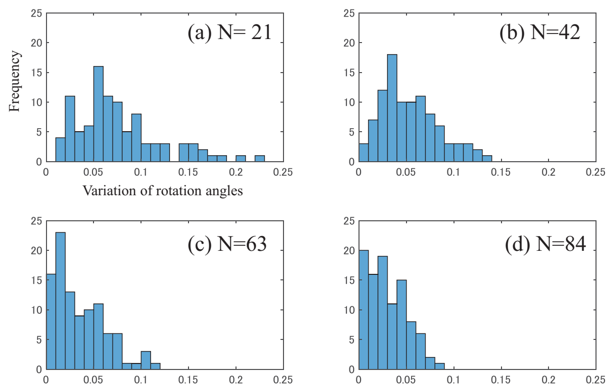


Fig. 4 Histograms of the total rotation angles.

3. Conclusions

In this study, several resolution conditions for the non-ideal models were compared in the contact simulation. The Monte-Carlo simulations of contact analysis were conducted using the non-ideal model pairs of each resolution condition. The distribution of the final posture of the surfaces in the contact state was analyzed. Non-ideal surface models were randomly prepared as two contacting planar objects. It is assumed that the surfaces are rigid and do not deform. The posture variation from the initial posture is expressed by two rotation angles. The Monte-Carlo simulations were performed 100 times for each resolution condition, N=21, 42, 63, 84, and 105. The results showed that the histograms of the rotation angles for resolution numbers N=63, 84, and 105 were similar, and we concluded that N=63 was the tentatively better resolution for the surfaces. However, the result could be applied only to the surfaces with the specific characteristics used in this study. In future work, verifications will be performed for each spatial frequency of the cutter mark.

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