5-Axis Control Ultraprecision Dexterous Micromachining of Möbius Ring

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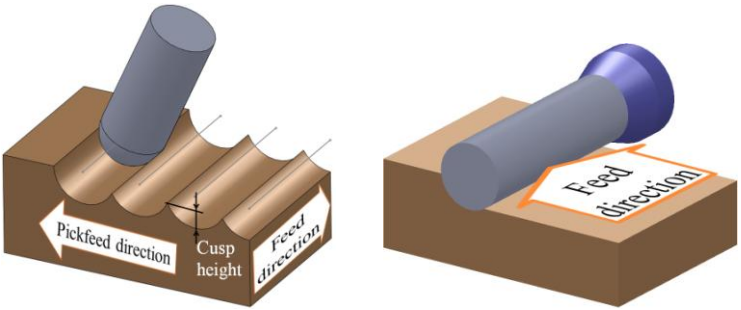
Abstract

5-axis control ultraprecision micromilling is devised by dexterously using the side edge of a ball end mill in machining ruled surfaces, together with the top edge. Thus, a new CAM system is developed to use the side edge of the ball end mill in combination with the top edge according to the surface shape. As an example of complicated microshapes, Möbius ring of 5 mm in diameter is subjected to machining experiment to validate the effectiveness of CAM system. As a result, it is found that the CAM system has the potential of dexterously and accurately creating a complicated microshape.

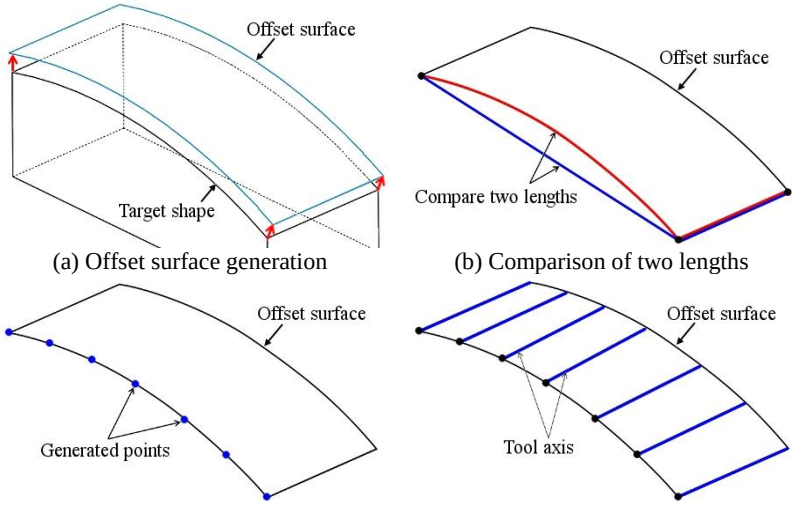
1 Introduction

In case of machining a complicated shape, a rotational cutting tool such as a ball end mill is generally used in ultraprecision micromilling as well as conventional machining. A ball end mill is moved discretely in the pickfeed direction. Then, the cusp is formed on the machined surface, as shown in Figure 1. The small cusp height



(a) Top edge cutting (b) Side edge cutting

Figure 1: Two ways of getting plain surfaces by milling



(a) Offset surface generation (b) Comparison of two lengths

(c) Generation of points along the edge (d) Line creation

Figure 2: Procedure of creating tool axis

is preferable in terms of the machined surface quality. Although a small pickfeed makes a low cusp height, it causes a long machining time. This problem takes place as long as the ball end mill is used.

In the study, 5-axis control ultraprecision micromilling of workpieces having a ruled surface is conducted by using both of the side edge and the top edge of a bal end mill, taking the collision avoidance into account. The machining method is named "Dexterous Micromachining" since it requires a skill and an ingenious device like a craftsman.

2 Development of CAM System

When using the side edge of a ball end mill, it is possible to shorten the machining time since the side edge cutting can machine large area at high cutting speed [1, 2]. Thus, a new CAM system is developed, which uses the side cutting edge in combination with the top edge according to the surface shape to be machined.

At first, the developed CAM system detects a ruled surface from the target shape. A ruled surface is a surface that can be swept out by moving a line in space. The most familiar examples are plane and curved surface of a cylinder or cone. In machining with the side edge of ball end mill, the CAM system generates the most suitable tool path with the collision avoidance between the tool and the workpiece.

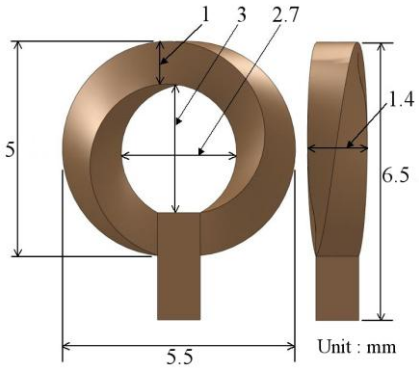


Figure 3: Möbius ring as a target shape

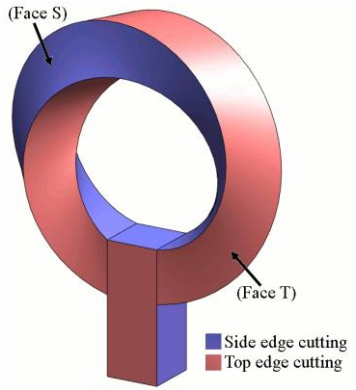


Figure 4: Decision of cutting edge

With regard to the ruled surface, the CAM system generates the tool path to machine with the side edge cutting. The procedure is illustrated in Figure 2. The collision between the tool and the workpiece may occur in machining complicated shapes. To avoid these collisions, it is necessary to evaluate all postures of the tool. The distance from the tool axis to the workpiece is compared with the amount of tool radius at a number of points along the tool axis. If the former is longer than the latter, no collision occurs between the tool and the workpiece. Additionally, in case that some tool postures are allowed in a cutting line, all distances from the tool axis to the workpiece are compared, and the longest one is selected in terms of the safety.

3 Machining Experiment and Result

To validate the effectiveness of the CAM system, a machining experiment is conducted. As an example of complicated shape, Möbius ring of 5 mm in diameter is selected, which consists of ruled surfaces. Detailed dimensions are shown in Figure 3. Material is brass. In the rough cutting, the top edge cutting is used by 3-axis control. On the other hand, the side edge cutting is used in the finish cutting. The tool path of rough cutting is generated by using a commercial CAM system, ESPRIT. In ultraprecision micromilling, a relatively large error occurs in setting the ball end mill and the blank workpiece. If a tool is changed to another one, the setting error inevitably occurs, thus leading to the deterioration in the surface quality. Therefore, a cemented carbide ball end mill having two long side cutting edges with the helical angle of 30° is used in this machining experiment.

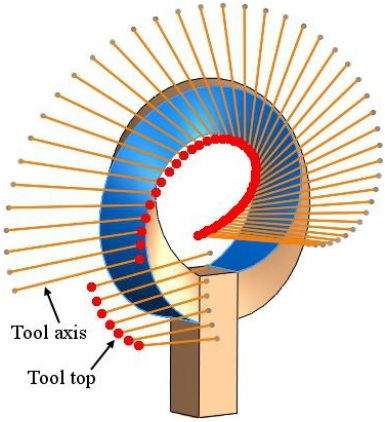


Figure 5: Side edge cutting tool path

Figure 6: Machined result

The CAM system can detect the ruled surface and judge whether the surface can be machined with side edge cutting or not, and generate the side edge cutting tool path. Figure 4 shows the faces to be machined by the side and the top edge. Figure 5 shows a part of the generated side edge cutting tool path together with the tool axis vectors. It is seen that the result of machining experiment has a good appearance in Figure 6.

4 Conclusion

In this study, 5-axis control ultraprecision micromilling is conducted by using the side cutting edge of the ball end mill in case of machining ruled surfaces, instead of the top cutting edge. A new CAM system is developed, which employs the side edge cutting in combination with the top edge cutting according to the surface shape. A complicated shape like Möbius ring of 5 mm in diameter is subjected to machining experiment. As a result, it is found that the CAM system has the potential of dexterously creating complicated microshapes with high efficiency.

References:

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[2] Takeuchi, Y., Nagasaka, M., Morishige, K., 1996, 5-Axis Control Machining with Top and Side Cutting Edges of Ball End Mill, Journal of Advanced Automation Technology, 8/1, 30-36.