Modelling of Drill Shapes by a Novel Predictive System

Kimio KAWAI[1], Anthony BEAUCAMP[2], Noriyuki IMAIZUMI[3], Masatoshi SAKURAI[4], Yoshimi TAKEUCHI[5]

[1,5]Department of Mechanical Engineering, Graduate School of Engineering, Chubu University, Japan

[2]Dept. of Micro-Engineering, Kyoto University, Japan, [3-4]OSG CORPORATIONS, Japan

[1]tm14004-4729@sti.chubu.ac.jp, [5]takeuchi_yoshimi@isc.chubu.ac.jp

Abstract:
There is a strong need for a new system to shorten the drill fabrication time, to reduce material costs, and to create new drill configurations by predicting their characteristics. Current drill shape prediction systems cannot comprehensively treat drill cross-section shape including the cutting edge, groove and so on, mathematically. Modelling would become more practical if the drill specification was mathematically formulated. This study reports the development of a system to predict not only cross-section shape but also various parameters from grinding wheels used in drill fabrication.

Keywords: Drill fabrication, Drill cross-section shape, Drill specification, Simulation software

1. Introduction

In recent years, the development of NC machining tools has allowed producing workpieces with complicated shape efficiently and accurately. Furthermore, new materials like CFRP have been introduced, thereby changing manufacturing conditions [1][4]. Accordingly, drills to make holes are also expected to feature both high machining accuracy and good processing performance in cutting such materials.

Today, new drills are fabricated by grinding cylindrical blanks on the basis of a designed shape. However, it is rather difficult to achieve the specified drill shape design with a single cut. Thus, a trial and error way of fabrication is performed by iteratively changing the grinding wheel shapes, grinding wheel setting, and grinding conditions, which takes a long time. Trial and error grinding also increases material cost and requires a long time before the actual mass production of new drills.

Therefore, this study aims at developing a simulation software to shorten the lead time and to reduce material costs in fabricating new drills. The simulation software predicts the drill cross-section shape by inputting the grinding wheel shapes, their setting condition and machining condition before the actual grinding process.

However, the current generation of simulation software has several problems. It takes a long time to accurately extract a drill contour with complex shape from the grinding wheel shape trajectory. In addition, if the extracted drill contour shape is not expressed as a mathematical function, it is impossible to obtain drill specifications such as rake angle, lead angle and so on, as shown in Fig. 1. With regard to the simulation software, the prediction function of drill specification is not fit for practical use.

In this study, a method is proposed to solve the above problem, by extracting an accurate drill cross-section shape using Delaunay triangulation on a large number of points, and performing outside/inside judgment on the resulting mesh. In addition, the system can predict drill specifications by use of mathematical function expressions.

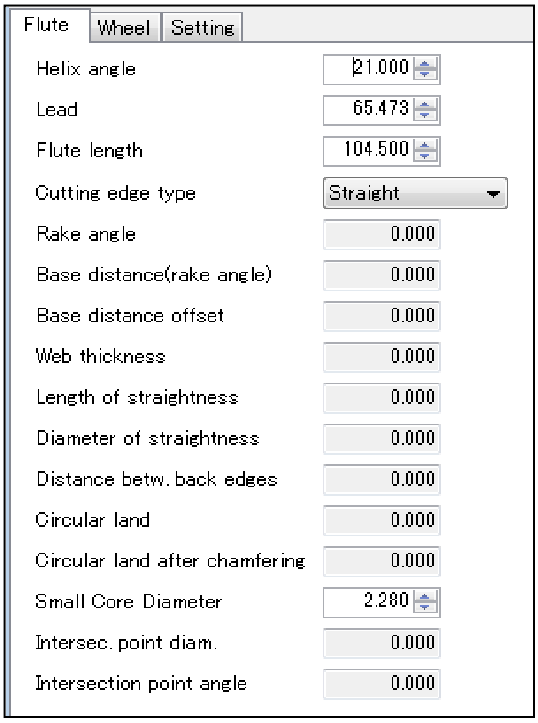


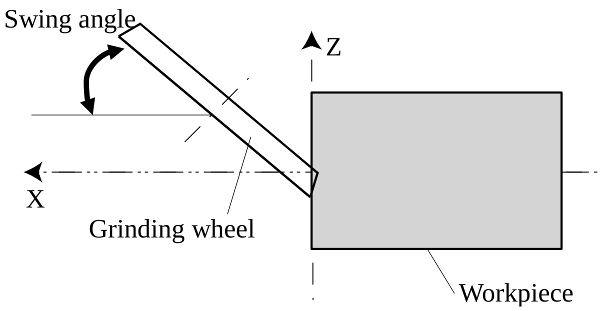
Figure 1: Drill specifications

2. Drill fabrication and its cross-section

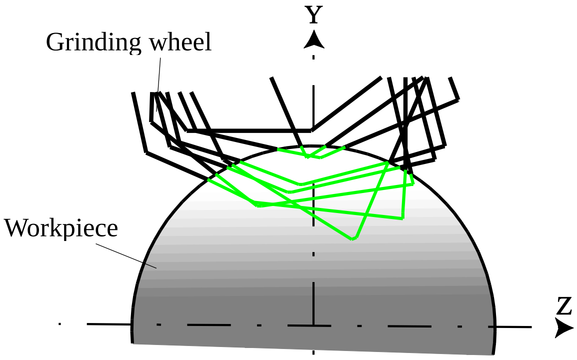
2.1 Drill fabrication by grinding wheels

First, we introduce the fabrication method of drills. At first, a grinding wheel suitable for the creation of the target drill groove shape is selected, and the grinding wheel is set against the cylindrical workpiece blank with a swing angle, as shown in Fig. 2(a). Then, the grinding wheel grooves the workpiece by a specified depth of cut.

The drill groove is formed by gradually increasing the depth of cut. At the same time, the workpiece is rotated to form the spiral groove. Drill shapes can be predicted by considering the combinational movement of the grinding wheel and the rotation of workpiece.



(a) Setting of grinding wheel



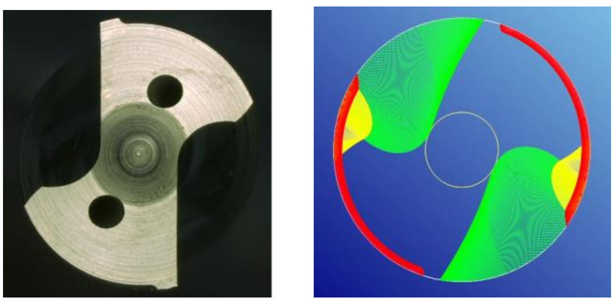
(b) Drill groove formation

Figure 2: Creation of drill shape by grinding wheel

2.2 Prediction of drill cross-section

Simulation software developed in this study can predict the drill cross-section by inputting both the grinding wheel shapes to be used for the fabrication and the processing conditions such as swing angle, depth of cut and so on, as shown in Fig. 2(b)[5].

In addition, it is possible to compare an actual cross-section shape of drill with the corresponding simulated one against the longitudinal direction, as shown in Fig. 3. The areas outlined in green, red and yellow in Fig. 3(b) stand for the portions to be ground by different grinding wheel shapes. Therefore, the actual drill shape corresponds to the left-over area.



(a) Front view of the actual drill (b) Front view of simulated cross-section

Figure 3: Actual and simulated drill cross-section

3. Prediction of drill groove

3.1 Extraction of external shape

In existing simulation software, the circumference of the grinding wheel is expressed as a series of many points forming the drill contour shape, as shown in Fig. 4. Superimposing successive circumferences of the grinding wheel along with the rotation of the cylindrical workpiece blank, allows forming the cross-section of drill grooves. As a result, the trajectory of the grinding wheel is expressed by a finite number of points.

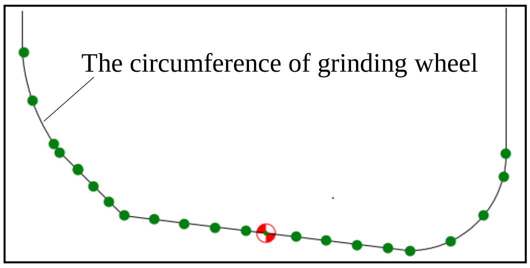


Figure 4: Circumference of grinding wheel expressed by a set of points

At the first stage, the extraction of the drill contour shape is performed by applying Delaunay triangulation [2] to the large number of superimposed circumference points. Delaunay triangulation enables to generate a number of small triangles by combining sets of three points without intersecting any other triangle, as shown in Fig. 5.

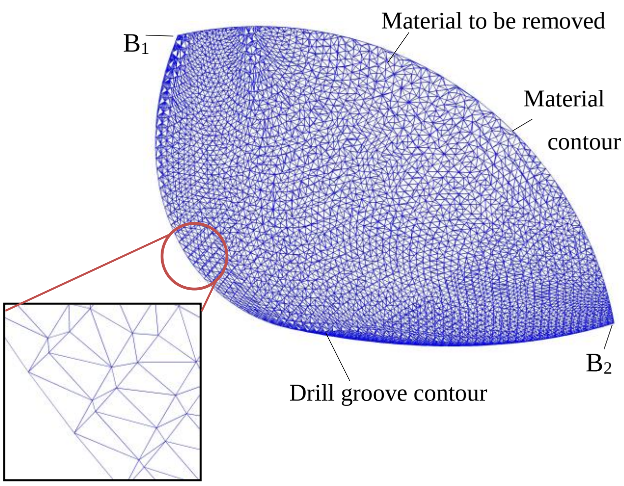


Figure 5: Application of Delaunay triangulation to superimposed circumferences of grinding wheel

At the second stage, the drill external shape, i.e. the drill groove, is extracted by processing the Delaunay triangulation, as illustrated in Fig. 6, where all points are numbered. Each edge of small triangles has the randomly numbered two points. Each edge is subjected to check whether or not it is overlapped with another edge. If there is an overlapped edge, it is removed, thus resulting in the fact that the edges forming the circumference of grinding wheel remain. For example, let us look at the triangular P_6-P_{12}-P_{41}. As seen from Fig. 6, it is easily found that the edges of P_6-P_{41} and P_{12}-P_{41} are removed by this operation. As a result, all internal points are eliminated, however, the remaining circumference consist of drill groove contour and the material contour. Thus, the later has to be eliminated to obtain the drill contour.

For the next step, two boundary points, B_1 and B_2 are found by using the inner product calculation for successive three points since the value greatly changes at the boundary. The use of boundary points enables to eliminate material contour.

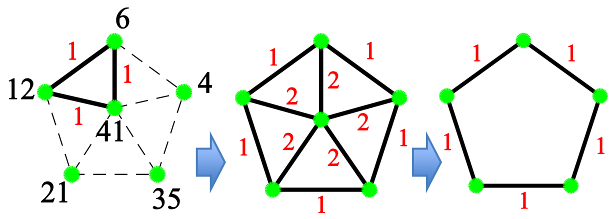


Figure 6: Removal of an internal point

3.2 Optimization of Delaunay triangulation

Drill contour shape points can be extracted by the above Delaunay triangulation method. However, it is impossible to accurately extract a drill contour shape by use of triangulation when the contour shape has concave portions, because the triangles may be constructed outside of the drill contour shape. Accordingly, when drill contour shape has such a concave portion, it is necessary to eliminate these triangles by the outside/inside judgment of points [3] after the triangulation, as shown in Fig. 7.

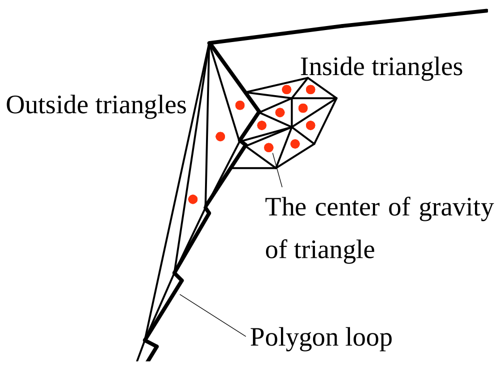


Figure 7: Outside/inside judgement of point

The outside/inside judgement makes use of the center of gravity of all of triangles. If the center of gravity exists outside of the polygon loop generated from the grinding trajectory of the grinding wheel, then it is judged be in the outside of the loop and removed. This judgement allows to predict the accurate drill contour shape.

The above judgement is applied to each grinding wheel trajectory to fabricate a drill. The hatched part in Fig. 8 shows the actual drill cross-section shape extracted.

4. Calculation of drill specifications

To obtain the drill specifications in advance to be manufactured, the system is devised to represent the drill contour shape points by a mathematical function. The use of all drill contour shape points makes the function complicated. Thus, the points necessary to calculate the specification are selected, and the mathematical function

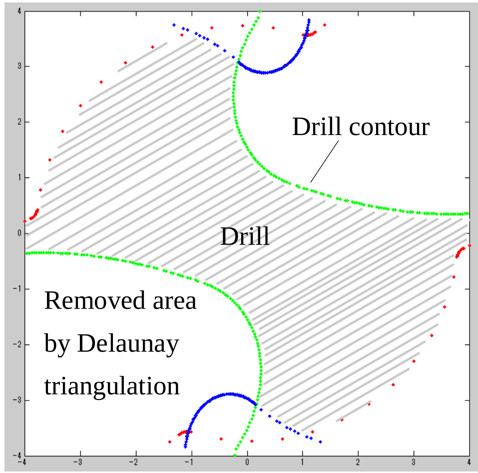


Figure 8: Drill cross-section shape

is formed by means of the least square fitting method, with enough accuracy to obtain the drill specification.

For example, let us explain how to calculate the rake angle, most important in the drill specifications, as shown in Fig.9. At first, the circle is determined, whose radius is the base distance from the cutting edge point of the drill contour shape. Several points closest to the circle on the drill contour shape points are chosen to get the approximated expression by least square method. The rake angle is obtained as an angle between Pi -Pt and Pt- Pc.

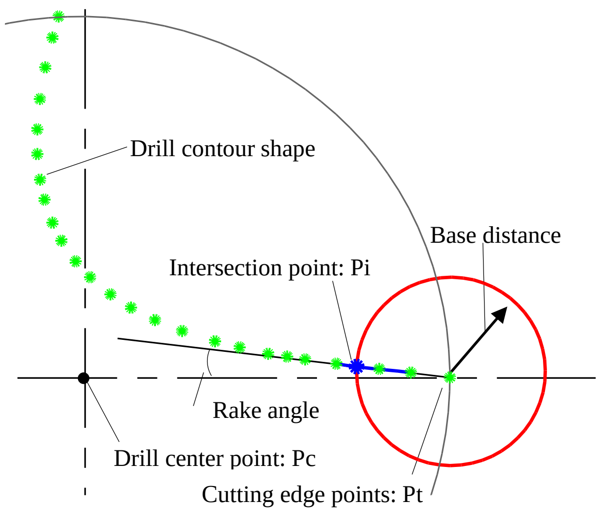


Figure 9: Calculation of rake angle

Other parameters can be calculated in a similar manner, together with cross-sections of drill grooves. As a result, all drill specification parameters are calculated, as shown in Table 1 and Table 2, where the base distance and the diameter of straightness are input values, respectively. As seen from Table 1, it is found that the calculated values show good correspondence with the reference values.

Table 1: Predicted drill specifications

Example 1		
Input value	Base distance (rake angle) (mm)	0.17
	Diameter of straightness (mm)	1.65
Various elements of Drill	Reference	Calculated
Rake angle (°)	5.41	5.4079
Web thickness (mm)	0.9	0.906
Length of straightness (mm)	1.769	1.76922
Distance between back edges (mm)	1.681	1.6854
Circular land (°)	85	87.37
Intersec. point diam. (mm)	4.59	4.5877
Intersection point angle (mm)	95.864	97.3163

Table 2: Predicted drill specifications

Example 2		
Input value	Base distance (rake angle) (mm)	0.25
	Diameter of straightness (mm)	4.2
Various elements of Drill	Reference	Calculated
Rake angle (°)	13.74	13.683
Web thickness (mm)	2.046	2.085
Length of straightness (mm)	3.06	3.091
Distance between back edges (mm)	6.572	6.497
Circular land (°)	55.113	54.738
Intersec. point diam. (mm)	9.614	9.6095
Intersection point angle (mm)	121.069	122.1369

5. Conclusion

This study aimed at creating a system for predicting drill specifications and drill cross-section shapes from grinding wheel shapes and cutting conditions, prior to fabrication. The results are summarized as follows:

(1) The correct drill cross-section shape can be extracted by applying Delaunay triangulation to a large number of points, and outside/inside judgement of triangles.

(2) The drill contour shape can be expressed with a mathematical function by use of the least square method, which then enables prediction of the drill specification.

References

[1] Shibata, M., Huruki, T., Toyoda, M., Watanuki, Y., Shimizu, T., 1993, Estimation of Grinding Wheel Profile for Generating Helical Flute and Cutting Edges of Drill, JSME, Vol.59, No.92 (C series), pp.927-931 (in Japanese).

[2] Iri, M., Koshituka, T., 1993, Computational Geometry and Geographical Information Processing, Second Edition, Kyoritsu Publisher, pp.126 (in Japanese).

[3] Suzuki, H., Kuwano, Y., Goto, K., Takeuchi, Y., Sato, M., 1994, Development of the CAM system for 5-Axis Controlled Machine Tool, JSPE, Vol.60, No.6, pp.832-836 (in Japanese).

[4] Sakamoto, S., Kajiwara, Y., Yasui, H., Moriguchi, H., Okida, J., 2007, Study on drilling process of CFRP (Carbon Fiber Reinforced Plastics): Effect of drill shapes on the drill-out of CFRP, JSPE, pp.59-60 (in Japanese).

[5] Kang, D., Armarego, E. J. A., 2003, Computer-Aided Geometrical Analysis of the Fluting Operation for Twist Drill Design and Production. I. Forward Analysis and Generated Flute Profile, MACHINING AND TECHNOLOGY, Vol.7, No.2, pp.221-248.