Development of intelligent system to minimize burr formation in face milling

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Abstract The exit burr generated in the face milling operation at the edge of the workpiece usually requires deburring processes to enhance the level of precision of the parts. This paper is to geometrically understand the formation of the exit burr in the face milling operation on the arbitrary shaped workpiece with multiple feature such as hole, spline, and arc so that we can suggest the cutting conditions and tool path to minimize the burr formation on the given workpiece in the early design stage.

The burr formation mechanism in each type of burr is classified based on the experimental results. A database is developed to store and predict burr formation results. A Windows based program is developed with the algorithm including three steps, i.e., the feature identification, the cutting condition identification, and the analysis on exit burr formation. We can predict which portion of the workpiece would have the exit burr in advance so that we can manage to find a way to minimize the exit burr formation in an actual cutting. Here, the idea of critical burr length is introduced as a criterion in optimization.

Keywords Burr expert system · Burr formation mechanism · Burr minimization · Critical exit angle · Face milling · Total tardiness

1 Introduction

An exit burr is regarded as being generated at the edge of the workpiece as the cutter moves out of the removed material. In order to remove the exit burr for enhanced cutting results, the deburring process is required after the face milling operation. Thus, this extra work might increase the cost of the cutting process and it also deteriorates the efficiency of the process by bottleneck in the manufacturing line. Gillespie pointed out that the deburring process might consume up to 30% of whole parts cost in fabricating precision parts [1]. This requires a method to predict the generation of exit burr in the early design stage using the simulation methods [2].

The purpose of this paper is to propose a general framework for geometric analysis of the formation mechanism of the exit burr in an arbitrary shaped workpiece in face milling operation and an optimization method to minimize the critical exit burr length based on the simulation. This study extends the previous geometrical analysis to the multiple feature workpiece with multiple tool path operations [3]. After identifying the workpiece and tool path, the algorithms are, in turn, programmed to predict the exit burr type and exit angle for given cutting conditions. By using this information in the design stage, we can reduce the occurrence of an exit burr in the milling operation so that the deburring process can be minimized.

2 Geometrical analysis on the formation of exit burr

2.1 Principle of exit burr formation

The characteristic location of a burr generated by the milling process is described in Fig. 1. In this study, the exit burr occurring at the edge of the workpiece as the cutter moves out of the removed material is mainly considered. According to the geometrical analysis, the formation of an exit burr has certain rules. One rule might be as follows.

\[
\text{IF } \theta < 90^\circ \quad \text{THEN } \text{identify exit burr region.}
\]

When we look at the plane view of the workpiece, we expect to have the exit burr from the intersection point on the workpiece edge to a certain direction as shown in Fig. 2 [3]. In Fig. 2, the exit
burr occurs at the intersection points C₁ and C₂. These extend to
the direction of (2) and (3) respectively. The exit burr extends to
the counter clockwise (CCW) direction based on the workpiece.

2.2 Burr type and exit angle

The burr shape is determined from the way the tool cuts at the edge
of the workpiece. We regard this idea as the exit angle, and this
will enable us to predict the type of exit burr in the simulation. Fig-
ure 3 illustrates the idea of exit angle. As the tool moves from A₁
to A₂, we calculate the angle between the tangent direction of tool
and the workpiece edge direction, and specify it as φ.

3 Multiple feature workpiece and multiple tool paths

3.1 Recognition of multiple features

The prediction of exit burr type is based on the edge character-
istics of the workpiece φ. Up to now, authors have developed
an algorithm to recognize individual geometrical feature from
a database of commercial CAD package. The geometrical fea-
tures include line segment, arc, circle, and free form splines. In
order to deal with the workpiece with multiple features, a group-
ing algorithm is proposed and validated [4]. The main idea of
this method is to categorize the geometrical features to form
a shape and then decide individual shape for the containment
test. Figure 4 shows the procedure to recognize the multiple fea-
ture workpiece from the initial recognition to the grouping and
finally to the assignment of direction of the shape.

The grouping procedure is to generate a virtual line which
is used to compare the starting and ending points of the line be-
fore specifying features like splines and arcs as shown in Fig. 5a.
Then, after selecting an arbitrary line, we proceed to find a line
with which the end points of previous line matches. Again, the
same procedure is iterated until the end point of the last line
matches with the starting point of the first line. This completes
one group.

This grouping procedure is completed when every group is
found and connected as in Fig. 5b.

After the grouping the direction of each group should be re-
arranged according to the containment test. This test is based on
the containment of one point in a group in the other group as in
Fig. 6. In CCW, if the addition of each acute angle by the arbi-
trary point P and every point of other group becomes +360°, we
conclude the point P is in the other group. Eventually the group
with point P is within the other group.

If the direction of the group is CW, then the total resulting
angle becomes −360°.

In Fig. 7, group2 and circle1 are contained in the group1, and
the direction of the group becomes clockwise.