Title
Model of a Burr Expert System

Authors
Balduhn, Alexander
Dornfeld, David A

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Alexander Balduhn
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Abstract— For the face milling process, many algorithms have been developed to optimize the tool path with respect to the burr formation process, and to predict the occurrence of burrs. However, collecting data to create the factual knowledge base for face milling burr expert systems has long been seen as too costly and time consuming due to the many parameters that influence the burr formation process in the face milling operation. A suitably designed part that captures in essence the distinguishing mechanisms of burr formation can be very beneficial in reducing the number of experiments performed. This paper describes the geometry of a workpiece and the machining strategy employed to generate the distinct face milling burr formation mechanisms. Measurement is limited to burr size parameters that directly influence the functionality of the workpiece edge and the ease of burr removal in further processing. The burr data collected after machining the specially designed workpiece is stored in the database. The database is designed using an Entity-Relationship model. This high level conceptual model helps structure the data in a fashion that renders this database highly suitable for planning applications. The database is designed to handle the most important queries raised by a process planner. For example, identifying insert materials that generate the smallest burrs for a given workpiece material, and so forth. The database also directly interfaces with the optimization programs like burr prediction and tool path planning that were developed for burr minimization in face milling. In addition, this database can be used as a standalone system, i.e. a “burr expert”, to recommend cutting parameters or tools for a specific material.

Keywords: burr expert system, face milling, edge quality, database.

1. Test part design

The first step to create a burr expert system is to design a workpiece that captures the distinguishing mechanisms of burr formation. To do this, several constraints have to be met by the “test part”. The first and most important step is to capture as much data as possible with one experiment. This reduces the total number of experiments, thereby reducing the wastage of material. The second objective is to make the burrs easily accessible for measurement. This in turn decreases the time needed to collect the data and to increase the quality of the measurements. Third, the wide variety of cutters used in industry requires the “test part” to be easily adjustable to the different cutting parameters, especially to different cutter diameters, due to the important influence of the cutter radius on the resulting exit order sequence. And finally, the part should capture the distinct burr formation processes. Tool entrance burrs, EOS and a special case called “push exit” burrs will be generated in the test part. These objectives resulted in the following “Test part” design shown in Figure 1.

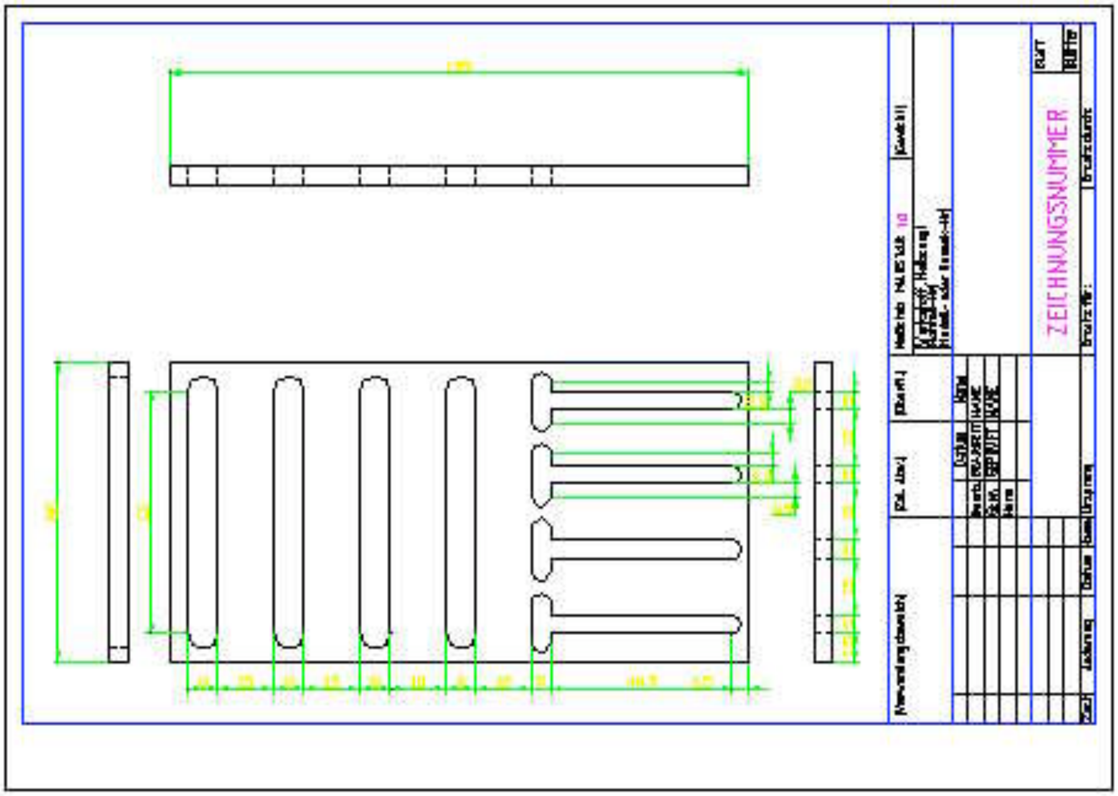

Figure 1. Design of the test part.

2. Experimental setup

Figure 2 shows the experimental setup for a 40 mm diameter cutter. The cutter is turning clockwise and moves from right to left while machining the workpiece. To cause the burr formation process, several slots are cut in the test part. One group of slots is arranged parallel to the tool path. Burr formation in these slots can be described by the exit order sequence. This implies that the measured burr height and burr thickness can be directly related to the occurring EOS. To calculate the occurring exit order sequence, an Excel spread sheet was developed. This spread sheet calculates the exit order sequence depending on following cutting parameters: cutter radius (mm), lead angle (deg), axial rake angle (deg), radial rake angle (deg), depth of cut (mm), and feed per tooth (mm). These calculated exit order sequences are related to a specific offset from the tool center that can be calculated using the angles. With this information it is possible to estimate, for each slot parallel to the tool path, which exit order sequence occurs. Using the Excel spread sheet it is possible to calculate the occurring exit order sequence for a tool with specific parameters, and a slot at an explicit distance to the tool center. It is also possible to calculate the distance a slot has to have from the tool center of a tool with defined parameters to archive a desired exit order sequence. This can also help to reduce the number of experiments, when it is desired to test exit order sequences that cause the lowest burr formation only. The other group of slots is cut perpendicular to the tool path. At these slots, push exit burr formation is caused. The position of these slots remains the same for all tool parameters.

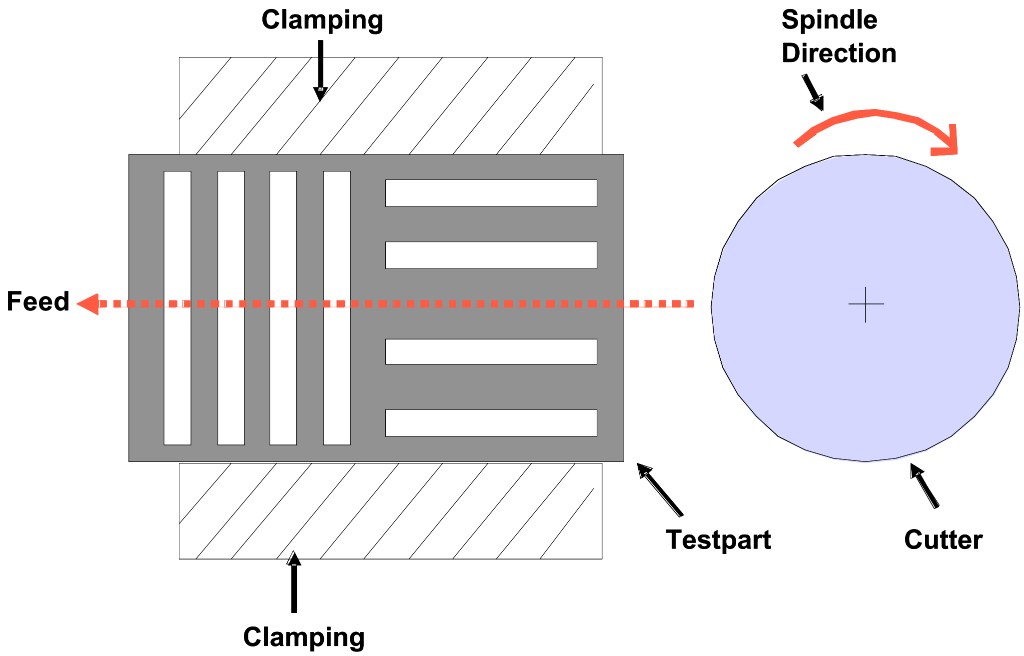

Figure 2. Experimental setup.

3. Burr measurement

The measurement method to quantify the edge quality is adopted from the method to determine the surface quality of a surface, Figure 3. The burr values collected are burr height and burr thickness. Figure 3 shows the principle of the method to determine the quality of a machined surface. To verify the quality of a technical surface, the surface is separated into several parts. In each of these parts, the distance of the highest peak to the deepest valley is measured. After this, the average of these values is calculated. In the proposed method, the edge is divided into 10 separate parts. In each of these sections, the distance from the highest, or the thickest, burr, to the deepest breakout is measured. The average of these values is taken. This gives a good picture of the achieved edge quality in the direction of the burr height and burr thickness.

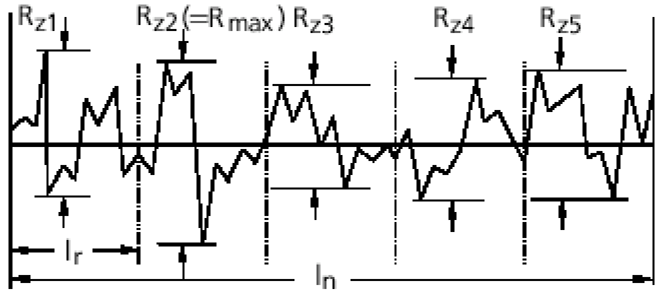

Figure 3. Principle of surface measurement.

4. Database design

The database has to suit several demands. First, it has to streamline the data in a way that is highly suitable for planning applications that employ the database. Second, the database should have functions to handle the most important queries raised by a process planner. For example, identifying insert materials that generate the smallest burrs for a given workpiece material, among other questions. Third, the database has to interface with other optimization programs for tool path planning and burr prediction. And finally, there should be some functions that help to predict the influence of a certain parameter on burr height and burr thickness. This also helps to reduce the total number of experiments necessary, because once the influence of a specific parameter can be predicted it is not required to make more experiments regarding this factor. Furthermore, the data that is stored in the database should contain all the information to answer the questions a process planner might have.

The database is programmed using an Entity-Relationship Model. The data contained in the database and the relations are shown in Figure 4. It can be seen that the data can be separated into six groups. The first group describes burr formation using burr height, burr thickness and shape. Several attempts have been made to classify face milling burrs by their shape, but all of them have been turned out to be too complicated for industrial applications. The second group consists of the machining parameters. These parameters are often not arbitrary because of cycle time constraints, and because of changing requirements of the different stages in the production; for example, roughing and finishing need different depths of cut. All these parameters have a big influence on the EOS, hence, the archived edge quality. The next group describes the tool that is used. It stores the parameters that are known to influence the edge quality as described by exit order sequence theory. The typical attributes of a tool are axial rake angle, radial rake angle, lead angle, diameter, and number of inserts. It also contains parameters that influence edge quality but are not accounted for by EOS. Wear effects prevents the use of any kind of insert material to machine, for example, aluminum alloys. It is also an often observed fact that a new insert results in better edge quality than a worn insert.

The occurring EOS and the material of the workpiece are stored separately. In the organizational group, it is listed if the burr was formed by exit or push exit burr formation process. Furthermore, the database keeps track of the number of times each experiment is repeated. This gives an idea about the accuracy of a given set of results.

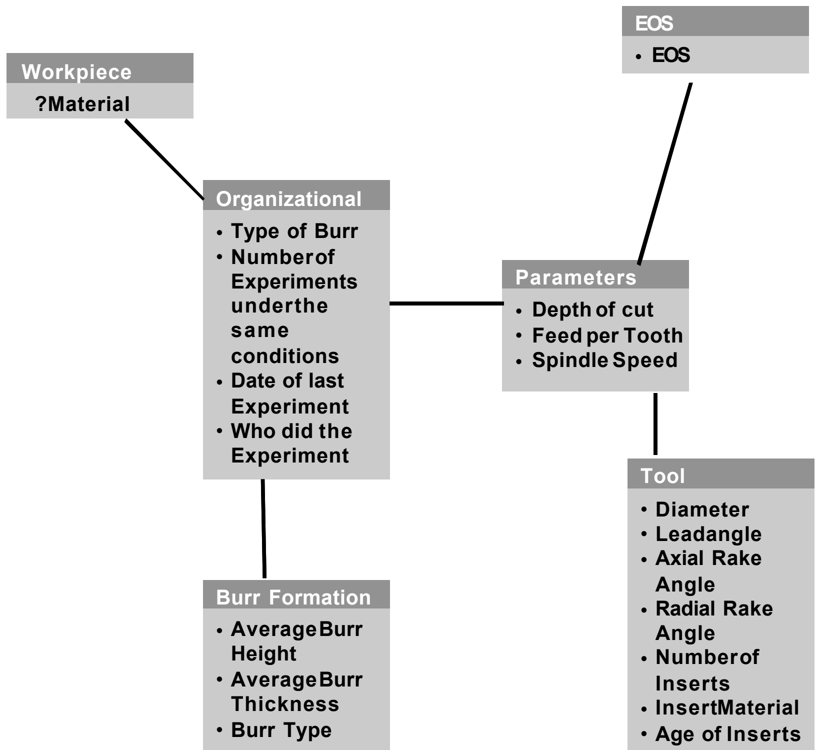

Figure 4. Stored Parameters.

The occurring EOS and the material of the workpiece are stored separately. In the organizational group it is listed if the burr was formed by exit or push exit burr formation process. Furthermore, the database keeps track of the number of times each experiment is repeated. This gives an idea about the accuracy of current set of results. All these parameters make it possible to describe the conditions of any face milling process in industry. Hence, the database is able to work as an independent burr expert to help optimize the machining process under given circumstances. For example, recommending a different axial or radial rake angle, or predicting the resulting edge quality. These functions are accessible by a Graphical User Interface that is connected directly to the database.

5. Conclusion

The proposed workpiece offers a huge advantage in gaining burr data for the face milling process. The proposed workpiece geometry allows for economical collection of the data needed for an expert system to predict burr formation. Storing this data in the designed database, and making it available to other software tools gives the user a powerful instrument to optimize the cutting processes with respect to the burr formation. This leads to major savings during the manufacturing process that may pay off the costs and time consumption involved with the experimentation required to fill up the database.