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Simulation-based deburring tool and process development

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A R T I C L E I N F O

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A B S T R A C T

This paper presents a simulation-based development of a new deburring tool and a CAM-assisted method to deburr intersections of cross-drilled holes. By analyzing and applying derived mathematic equations to construct a three-dimensional view of these contours, a cutting edge specifically aligned to the intersection is developed. The intervention conditions and the synchronization of the tool and numeric control approach require 3-axis machining. This ensures a uniform chamfer along the circumference of the intersection despite the fluctuating cutting conditions. CAM-assisted deburring reveals the exact position of the burr, allowing the deburring tool to adapt to cross-drilled holes of different diameters.

1. Introduction

During the cutting of material, many manufacturing processes cause burrs on the workpiece. This includes the process of cutting material with a geometrically defined cutting edge [1]. Due to the surface roughness, it is not possible to ensure a complete burr-free machining by using an appropriate resolution of the used measuring methods to identify this constraint of machined edges [2–4]. To this day, neither a uniform definition nor a directive regarding burr-free components exists. Highly stressed components in the field of hydraulics are required to have, for example, edges with the same chamfer width. Whereas a slight burr root is tolerated if a sharp edge is necessary to ensure the functionality of components. However, it is a prerequisite that the excess material does not detach itself during the operating phase [5]. There is a multitude of definitions for the term ‘burr’. Schäfer laid the groundwork in the 1970s by summarizing the already existing definitions of this term. In this way, he developed a general definition of the term ‘burr’ [6]. Beier picked up on this definition and completes it with further explanation:

> ‘*Burrs are undesired but mainly unavoidable. A burr is a material accumulation, which is created on the surface during the manufacturing of a workpiece. It extends over the intended and actual workpiece surface and has usually smaller volume in comparison with the workpiece.*’ [7]

On the one hand, burr formation bears an immense potential to cause injuries for assembly workers. On the other hand, burrs lead to a qualitative deterioration of the function surface or endanger the piping system functionality (e.g., main oil duct, cylinder heads or rails, etc.). Additionally this results in a considerable time-consuming testing phase. Components whose reliability is influenced by burrs are subjected to a 100% visual inspection. Although, this leads to higher costs and longer processing times [8]. Contours which were not deburred can, especially in a load-carrying and dynamic system, lead to a complete breakdown during the utilization phase due to the detachment of burrs (e.g., safety relevant hydraulics) [9]. A particular challenge poses the deburring of the inside of a component, which is important, e.g., for the insertion of cross-drilled holes. The term ‘cross-drilled holes’ describes holes that cut into or penetrate already attached drillings or precast channels of a component [10]. Aurich shows in [11] that even modification of the point geometry on the drill cannot avoid the formation of burrs, which therefore results in a plastic evasion of the material into hollow spaces (e.g., pre-drilled holes). Due to the restricted accessibility of the intersection, a series of tool concepts have been developed to deburr drill-hole intersections with a geometrically defined cutting edge [12].

These tools can be subdivided into combination tools or deburring tools with an exposed or with a cutting edge integrated into the shaft. Combination tools combine working processes such as milling or drilling with the deburring process in one single tool. The area around the cutting edge is equipped with a foldout cutting edge within the drill. This invention enables, for example, the drilling and simultaneous deburring of the bore entrance and exit [13,14]. An exposed tool cutting edge can be subdivided into a cutting edge that is movable to the base body [15–17] or completely rigid [18,19]. Is the cutting edge, however integrated into the shaft, then it is folded out from the base body when the pre-drilled hole has been reached. Therefore, deburring tools are equipped with spring-like components or elastomers (e.g., [20–23]) or are based on the change of rotational speed or direction of rotation (e.g., [24,25]), as well as an additional control element [26–28]. All tool concepts with a geometrically defined cutting edge are based on a rotational basic movement and try to remove the burr with high rotational speed but without any knowledge of its position. Benchmarks [29,30] of already existing deburring tool

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concepts, which have been specially developed for deburring cross-drilled holes, demonstrate the requirement of new tools and procedures. Over the last couple of years, statistics by the Fluid Power Association have shown an increasing demand for new inventions in the areas of mobile and industrial hydraulics [31].

2. Modeling

The simulation model consists of the synchronization of a numeric control and a tool-based approach (Fig. 1). The implementation was done using Matlab® development environment. This numeric control approach aims to mathematically describe the intersection curve of two touching cylinders. This will help to guide a tool cutting edge along this intersection curve and to cut off the burr roots precisely. Concurrently, it will be possible to deburr a much wider range of drilling intersections due to targeted tracking of the machine tool.

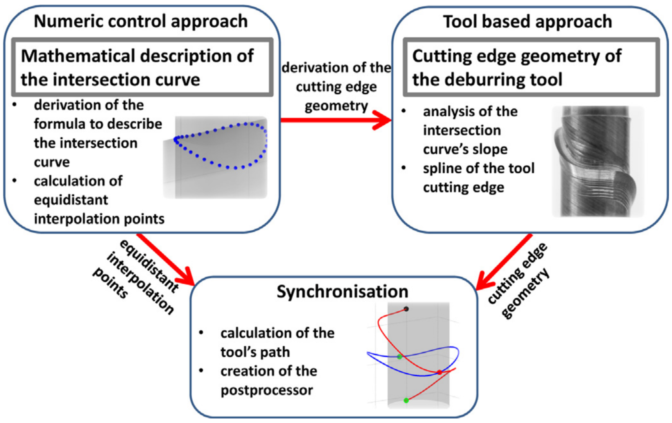

Fig. 1. Schematic of the modeling process.

The tool-based approach, on the other hand, aims to develop a cutting-edge geometry that focuses on the various intervention conditions of cross-drilled holes. It also creates a uniform chamfer width along the circumference of the drilling intersection. The synchronization of both approaches has to provide a reliable removal process of the primary burr (burr formation due to the drilling process).

2.1. Mathematical description of the intersection curve

An intersection curve is a higher-order mathematical function and can be fully described by using the following three parameters:

- radius of the pre-drilled hole r_p
- radius of cross-drilled hole r_c
- axis offset a_m (between pre- and cross-drilled hole axis)

A rotation of the pre- or cross-drilled hole is not considered within this paper.

An axis offset is a specific distance a_m between the pre- and cross-drilled hole. If the axis offset equals zero, the cross-hole axis is perpendicular to the pre-drilled hole axis as well as in the XZ plane (see Fig. 2). A positive axis offset leads to movement of the cross-hole toward the positive Y-axis. If the axis offset is $a_m > r_p - r_c$ then the entrance and exit curve merge to one single curve. Variations of drilling-hole radiuses or drilling with an axis offset will lead to a change of form and position of the intersection curves.

The mathematical equations for the intersection, including the positive critical axis offset (Fig. 3) without any rotation, can be derived from the parametric equations of the pre- and cross-drilled hole descriptions. By equating these two equations, the intersection curve can be determined. After a long but simple conversion, the following mathematical equations are achieved:

$$x_i = r_c * \sin(\beta_i) \tag{1}$$

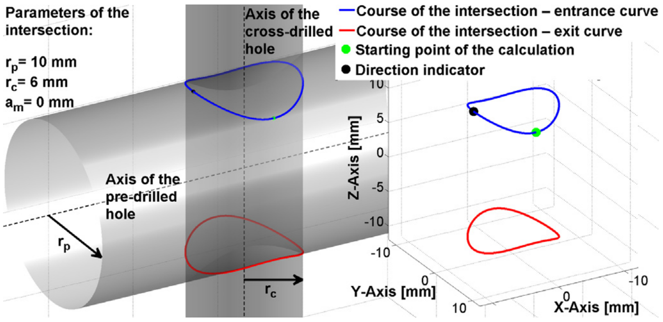

Fig. 2. Presentation of the intersections $a_m = 0$ (subcritical axis offset $a_m < r_p - r_c$).

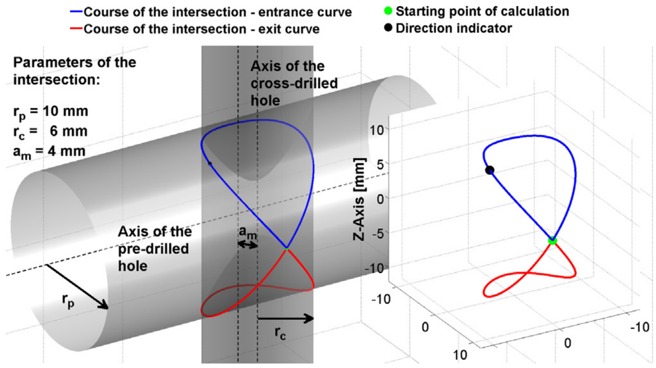

Fig. 3. Presentation of the intersections $a_m = r_p - r_c$ (critical axis offset).

$$y_i = r_c * \cos(\beta_i) + a_m \tag{2}$$

$$z_i = \pm\sqrt{r_p^2 - y_i^2} \tag{3}$$

The central angle β_i in the mathematical equations (1) and (2) is, up to and including the critical axis offset (for $a_m \le r_p - r_c$), defined by the following mathematical equation:

$$\beta_i = \frac{i * 360^\circ}{n} \tag{4}$$

In this case, i is a counter, which runs until the total number of calculated points (n) is reached. The total number of increments in turn has an influence on the size of the central angle β_i.

2.2. Calculation of the interpolation points

A total number of points (n) on the intersection curve can be calculated by using the mathematical equations (1)–(3) (see Fig. 4). These increments are distributed on the intersection curve in such a way that the central angle between two increments is

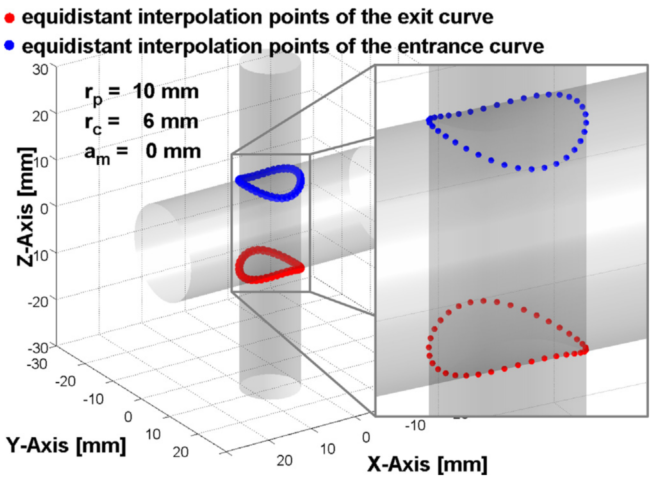

Fig. 4. Intersection curve divided in 36 equidistant interpolation points.

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