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GEOMETRIC MODELING OF TWIST DRILLS

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ABSTRACT
Accurate geometric models of twist drills are needed to determine the required grinding wheel profile for generating a given drill flute profile design, as well as, for finite element simulations of the drilling process. This paper presents a method to create accurate models of two-flute conical twist drills using analytical equations to generate drill flute profile needed for production of twist drills with straight lips and solidmodeling techniques to generate geometric models of twist drills. Boolean operations are used to mimic the drill manufacturing steps and generate the fully designed drill.
Keywords: twist drills, geometric modeling, solidmodeling techniques

1. INTRODUCTION
Drilling is one of the most commonly performed material removal processes, being increasingly popular over the years. The aforementioned process is used to create a cylindrical hole in a solid section of a work piece material. When using mechanical methods and tools, drilling involves rotational and linear feed motions. Invented almost two centuries ago, today's twist drill is a general purpose tool used to produce holes ranging in size from very small (0.1 mm) to quite large diameters (well over 100mm). Although the conventional drilling tool is very common in industry, it is characterized by a complex geometry.
Galloway [1] initiated a formal study of drill geometry in his paper where he discussed several aspects of the drilling process and gave a sophisticated analysis of drill point sharpening based on a conical grinding concept for straight lipped drills shown in figure 1.

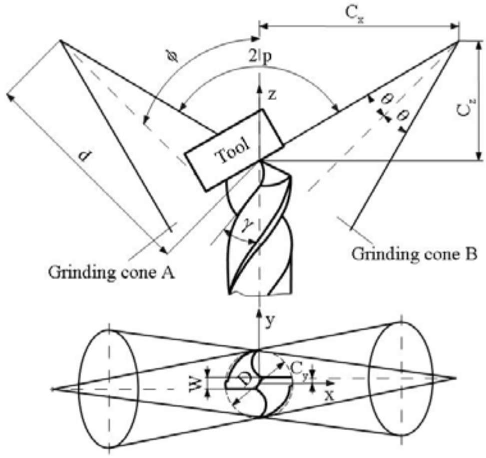

Figure 1. Drill point sharpening based on a conical grinding concept

In this work the geometry in the vicinity of the drill lips was thoroughly studied including methods of specifying and measuring the lip clearance angle. Equations for the relevant part of the flute geometry required to give straight lips were derived together with expressions for lip clearance and rake angles along the drill lips. Galloway pointed out that the flank surface of the drill would be fully determined if the semi-cone angle θ, and the cone apex position with respect to the drill axis, denoted by parameter *d* and *s* in Figure 1, were known in addition to the specified point angle *2p*, web thickness *W* and diameter *D*.

Subsequent researchers built on Galloway's basic framework and extended his analytical equations to develop computer-based models. Fujii et al. [2,3] developed algorithms to develop drill models by computer. The drill geometry was analyzed by considering the "slicing" of the drill by arbitrary planes. A computer model was also developed to design a twist drill. Vijayaraghavan et al. [4] developed an automated drill modeling tool in Solidworks. The tool uses Solidworks to generate a 3D model of a drill based on manufacturing parameters of the drill supplied by the user. The tool outputs the drill in a variety of solid geometry formats which can then be meshed and used in different FE modeling packages. Kyratsis et al. [5,6] developed software routine, which creates parametrically controlled drill geometries and using different cutting conditions, achieves the generation of solid models for all the relevant data involved. This routine can simulate the drilling operation using 3D solids for both the drilling tool and the work piece. Those models were used in order to simulate the penetration of the tool inside the work piece and subsequently led to the generation of 3D solid models for the undeformed chip and the cut work piece [5]. This routine also calculates the thrust force of both the cutting areas of the tool, main edges and chisel edge, simultaneously [6].

This paper deals with establishing procedure, based on Galloway's approach, for development of CAD tool for automated modeling of two-flute conical twist drills. This procedure involves analytical equations to generate drill flute profile needed for production of twist drills with straight lips and solidmodeling techniques to generate geometric models of twist drills which mimic the drill manufacturing steps. Accurate geometric models of twist drills output by this CAD tool are needed to determine the required grinding wheel profile for generating a given drill flute profile design, as well as, for finite element simulations of the drilling process.

2. METHOD

2.1 Manufacturing of two-flute drills

Drill manufacturing consists primarily of two grinding steps, namely grinding the flute faces and grinding the flank faces. The parameters of these grinding operations determine the geometric parameters of the drill. Parameters such as point angle and web thickness are implicit functions of the drill's manufacturing parameters.

During flute grinding the grinding wheel rotates in-place with the drill simultaneously rotating about and moving down its axis. The dual motion of the drill controls the helix angle of the flute and the position and profile of the grinding wheel controls the cross-section of the drill flute. In a two-flute drill, this is performed twice at orthogonal positions to generate both flutes. During flank grinding, the grinding wheel rotates about a fixed axis to form a "grinding cone" of cone semi-angle θ, shown in Figure 1, and the dill rotates "in-place". This grinding is also performed twice from symmetric positions to generate both flank surfaces. These flank surfaces can be considered as sections of the grinding cones.

2.2 Modeling of flute faces

The cross-section of the flute is dependent on the shape of the grinding wheel used for grinding it. The cross-section of the drill has to be designed such that it generates a straight secondary cutting edge when the flanks are ground. Hence, the shape of the flute grinding wheel is dependent on the specifications of the drill that is being ground. The cross-section of the flute can be divided into 6 sections, as shown in Figure 2. Sections 1 and 2 are un-ground parts of the drill-blank and are arcs which make up a circle.

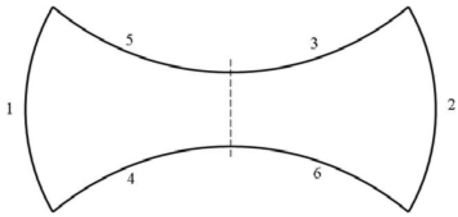

Figure 2. Flute cross-section

Sections 3 and 4 can be described by the following polar equation [1]:

$$\nu = \arcsin\left(\frac{W}{2 \cdot r}\right) + \frac{\sqrt{(2 \cdot r)^2 - W^2}}{D} \cdot \frac{\tan(\gamma)}{\tan(p)} \tag{1}$$

where r is a variable in the polar equation, and is varied from $W/2$ to $D/2$, γ is the helix angle. This polar equation makes sure that the flank section produces a drill with a straight cutting edge. Sections 5 and 6 do not contribute much to the cutting performance of the drill and only need to be optimized to provide rigidity. For simplicity, they can be modeled as symmetric to sections 3 and 4, respectively [4].

3D solid model of flute faces is obtained when the flute cross-section is swept, i.e., rotated and translated about its axis. The sweep matrix is given as:

$$S = \begin{bmatrix} \cos\varphi & \sin\varphi & 0 & 0 \\ -\sin\varphi & \cos\varphi & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & \frac{P \cdot \varphi}{2 \cdot \pi} & 1 \end{bmatrix} \tag{2}$$

where $0 \le \varphi \le \frac{2 \cdot \pi \cdot L}{P}$, L is the length of cylindrical fluted portion of the drill and P is pitch, which is expressed as:

$$P = \frac{D \cdot \pi}{\tan(\gamma)} \tag{3}$$

2.3 Modeling of flank faces

The vertices of the grinding cones, as shown in Figure 1, are as follows:

$$\begin{aligned} C_x &= \mp(d \cdot \tan\theta \cdot \cos\phi + d \cdot \sin\phi) \\ C_y &= \pm s \\ C_z &= d \cdot \cos\phi - d \cdot \tan\theta \cdot \sin\phi \end{aligned} \tag{4}$$

where ϕ is the angle between the projections of the cone and drill axes on a plane parallel to these axes, which can be expressed as:

$$\phi = \pm(p - \theta) \tag{5}$$

The upper sign in the previous equations refers to the right grinding cone, while the lower sign refers to the left grinding cone.

Drawing the cone axes at these vertices and creating a virtual cone, with the semi-cone angle θ, to performe a Boolean subrtact cut one can generate the flank faces of the drill.

3. RESULTS

From the above analysis, the following parameters, geometric and manufacturing, are needed to completely describe a drill: diameter of drill, web thickness, helix angle, point angle, grinding cone angle and Galloway's parameters. A drill geometric model generated by established procedure, for the following set of parameters *d*=11mm, *W*=1.8mm, γ=30^o, *2p*=118^o, θ=30^o, *d*=5.5mm and *s*=1mm, is shown in Figure 3.

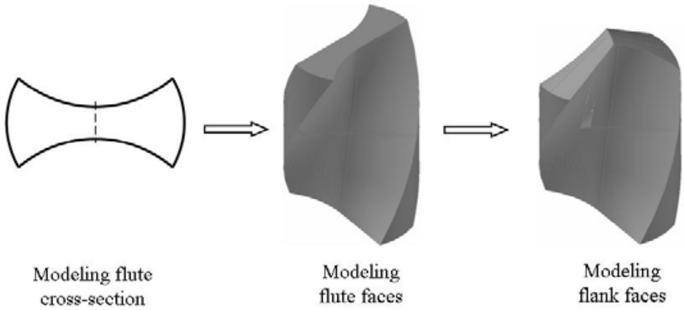

Figure 3. Generation of drill geometric model

4. CONCLUSION

The novelty of the this research is that the drill modeling procedure, that is going to be embedded in a commercial CAD environment by exploiting its modeling and graphics capabilities, has been established. Established procedure is based on geometric and manufacturing drill parameters and enables producing pure 3D solid model of the two-flute twist drill. These 3D geometric definition provide the data required for a number of downstream applications, i.e., finite element analysis, 3D scanning of tool geometry etc.

5. REFERENCES

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