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A study of computer-assisted analysis of effects of drill geometry and surface coating on forces and power in drilling

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ABSTRACT

The success of continuous improved drill performance in cutting applications has to date largely been based on significant advances through tool surface coatings and modifications of drill point geometry, i.e. optimisation of the rake angle distributions along the drill lips and the chisel edge. It has been recognised that due to the complexity of equations for the force and power predictions, computer assistance is needed. Consequently, this paper presents the results of a systematic – computer-assisted – study focused on determining, and describing, from a mathematical point of view, the relationship between the drill point geometrical features and the performance measures as assessed by the cutting forces and power in drilling. This is followed by a study of predicted influences of drilling variables on the generated thrust, torque and power. The results are presented for different types of modern commercial tool surface coatings and work-piece materials. It is suggested that this sort of information may be used, by both tool manufacturers and users, to assist in the optimisation, and selection, of the drill point geometrical features for 'best' performance.

1. Introduction to the effects of drill geometry on forces and power in drilling

The models and/or software applications for prediction of thrust, torque and power in drilling for commercially designed drills are quite complex and include a set of equations which relate the thrust, torque and power to the drill point features (D, $2W$, δ_0, ψ, $2P$, and Cl_0), cutting conditions (f, n), number of elements characterising the lip (M_L) and chisel edge (M_C) regions and the basic cutting quantities (r_l, β, τ including edge force coefficients K_{IP}, K_{IQ}) as well as coefficients C_{IP} and C_{IQ} for discontinuous chip formation obtained from the orthogonal cutting data base for a particular tool/work-piece material combination (Armarego, 1996). It has been stated in the literature (Armarego, 1996; Zhao, 1994; Armarego et al., 1997) that values of the geometrical drill point features such as $2P$, δ_0 and $2W$ vary from manufacturer to manufacturer and more importantly from batch to batch. The geometry of the chisel edge region also varies widely depending on the point sharpening method used and the control of the sharpener settings (Armarego, 1996; Zhao, 1994). Considering more closely this information it seems to be crucial to obtain accurate data about the actual specified drill point features, and, if necessary, to use the 'as measured' data, rather than the nominal values 'provided' by the tool manufacturer, in predictive

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Nomenclature

Symbols

D	drill diameter
$2W$	web thickness
f	feed rate
r_l	chip length ratio
$2P$	point angle
Cl_0	lip clearance angle
n	drill revolutions
β	friction angle
ψ	chisel edge angle
δ_0	helix angle
δ_w	setting angle of the grinding wheel
τ	shear stress in the shear zone (plane) (N/mm^2)

drilling models for quantitatively reliable thrust, torque and power predictions.

The drilling action itself is a complex cutting process controlled principally by the geometry of a given drill dictated mainly by the positions and lengths of the lips and chisel edge regions. The cutting action on the drill lips has been reported to be similar to that of the 'classical' oblique cutting process but with variable cutting speeds, inclination angles and normal rake angles along the lip from the chisel edge corner to the outer corner. By contrast, the cutting action at the chisel edge has been found to be much closer to that of 'orthogonal' cutting at relatively high negative rake angles and very low cutting speeds resulting in discontinuous chip formation. In the areas very close to the drill axis a type of 'indentation' process can be considered to occur where dynamic clearance angle is zero or negative.

The work presented in the following Sections was undertaken by the author of this paper and Dr. Armarego, from the Melbourne University, was the supervisor until his death in 2003. Except where stated the work reported is the results of the author's own research work with reference to the source (Audy, 2002).

2. Analysis of cutting action at drill point geometry

The investigations outlined in Sections 2.1 and 2.2 were set up to analyse the lip design and chisel edge region of twist drills prior examining the effects of drill point modifications on predicted thrust, torque and power in drilling.

2.1. *Lip design and its reported effects on the drilling forces*

Fig. 1 shows the geometry of, and the forces acting on an element at, the lip region of a conventional general purpose twist drill. From the mathematical point of view the drill lip region can be considered as a sum of a number of different elemental oblique cuts controlled principally by their own tool geometry and cutting conditions ($V_W = V$, γ_n, λ_s, t, δb_i, r_i, f, n). The first three values – namely V_W, γ_n, λ_s – are found from the specified drill point geometrical features (D, $2W$, δ_0, and $2P$) at each elemental radius r_j; the oblique cutting forces are determined from the 'classical' oblique cutting analysis for the element radius of r_j, areas of cut δA (= $t\delta b$) found from the cutting conditions, f and b; the fundamental oblique cutting tool geometry, γ_n and λ_s, and the basic cutting quantities, τ, β and r_l, and the edge force coefficients, K_{IP} and K_{IQ}, obtained from the orthogonal cutting data bank.

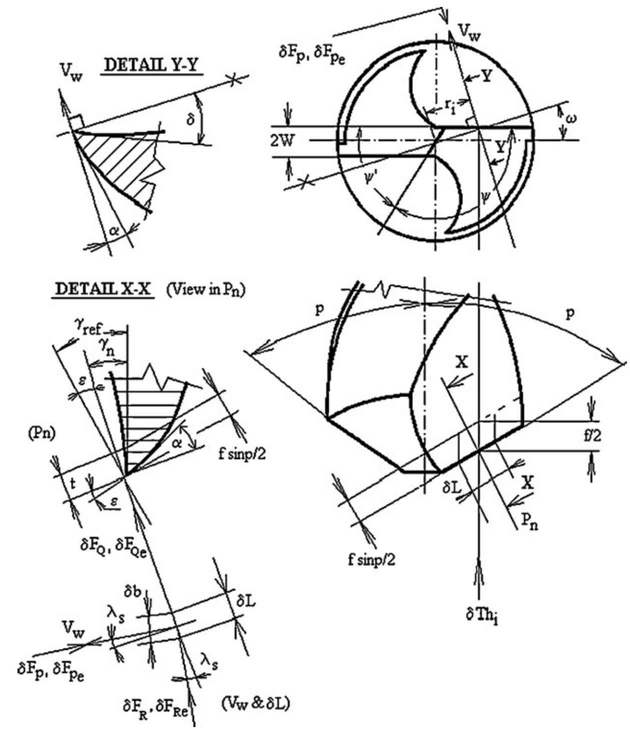

Fig. 1 – Geometry of, and the forces acted at, the lip regions of a conventional drill. Refer Armarego (1996).

The thrust force (T_h) and torque (T_q) at the drill lip region can be calculated via the sum of elemental values (δT_{h1j}) and (δT_{qj}). The required values for both the elemental thrust force (δT_{h1j}) and elemental torque (δT_{q1j}) can be calculated from the 'oblique' cutting force components (δF_P, δF_Q, and δF_R) and associated 'edge' force components (δF_{Pe}, δF_{Qe}, and δF_{Re}), the mean radius (r_i), the number of selected elements (M) on the lip region, i.e. cutting edge length ($\sum \delta L$), and the drill geometry as documented by the same Fig. 1.

Mathematical expressions to calculate drilling forces from a particular drill lip geometry and cutting conditions are shown in Eqs. (1)–(18).

Thrust force (T_{hl}) and elemental thrust force (δT_{hlj}) at the drill lip region:

$$T_{hl} = \sum_{j=1}^{M} \delta T_{hlj} \tag{1}$$

where the elemental thrust force at the lip region $\delta T_{hlj} = \lfloor(\delta F_Q + \delta F_{Qe}) \cos\varepsilon \sin p - (\delta F_R + \delta F_{Re}) (\cos\ \lambda_s \cos p + \sin\lambda_s \sin p \sin\varepsilon)\rfloor$, and the required angle (ε) can be obtained by projecting the speed vector (V_w) into the normal plane (P_n), and