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Drilling simulations using a 3D CAD system

Panagiotis Kyratsis, Konstantinos Kakoulis, Emmanuel Maravelakis

***Abstract*—Drilling is considered to be one of the mostly used processes for holemaking. Researchers have followed different approaches for the drilling simulation. Different mathematical tools offer a great deal of help in describing difficult 3D equations in space. Due to the continuous onward usage of CAD systems in all industries, new applications based on the Application Programming Interface (API) that each one offers, are under development. The present paper uses a general purpose CAD system and its API in order to create a kinematic model that parametrically controls the twist drill tool geometry. Introducing different tool parameters and cutting conditions, a series of 3D solid models for the tool, the workpieces and the undeformed chips are created and the resulted thrust forces can be predicted in both the main edges and the chisel edge. The proposed methodology is experimentally verified and provides the basis for a series of new applications in manufacturing.**

Keywords— drilling process, CAD, simulation

I. Introduction

Drilling is widely applied in manufacturing operations and it is the most commonly used method for holemaking in industry. Especially nowadays that nonmetallic materials are used in a variety of applications, from automotive to aerospace, drilling has become extremely important. A series of methodologies for the drilling process simulation have been developed from a variety of researchers. While some of them are using experimental work in order to derive equations calculating the thrust force developed during drilling, others deal with the creation of finite element (FE) models coupled with experimental verification results.

Although the kinematics of the drilling process is very simple, the tool geometry is significantly complex. The mathematics behind 3D modelling is considerably complex and highly trained specialists are required. This is a big drawback, especially when considering the numerical simulation of a number of phenomena such as burr formation, cutting forces prediction, tool deformation, temperature distribution etc. At the same time, while the chips produced have only limited space for their removal through the flutes of the tool, the drilling simulation becomes considerable more complicated.

Panagiotis Kyratsis, Konstantinos Kakoulis
Technological Education Institution of Western Macedonia
Greece

Emmanuel Maravelakis
Technological Education Institution of Crete
Greece

II. Drilling simulations

Galloway [1] and Tsai and Wu [2, 3, 4] were the first to develop mathematical models for standard drill geometries (i.e. conical, hyperboloid, ellipsoidal) in terms of their grinding parameters. Sambhav et al. proposed a methodology for the model of different twist drills with a generic point geometry using NURBS. A detailed basic model for the fluted twist drill with sectional geometry made up of arcs and straight lines was presented in terms of bi-parametric surface patches. The coordinates of cutting lips and chisel edges were obtained as a solution to a surface-curve intersection problem. MATLAB™ was used for this mathematical model [5].

Typical approaches for the numerical modeling of metal cutting, offer the Lagrangian and Eulerian methods. Bagci and Ozcelik predicted the drill bit temperature, when AISI 1040 steel and Al7075-T651 is machined using Third Wave AdvantEdge™, while Li and Shih treated the drilling cutting edges as a series of straight cutting edge primitive cutting tools, consisting of various cutting angles, and they simulated the cutting forces and the material deformations of each primitive cutting tool [6, 7]. Li and Liang have used the DEFORM™ software in order to simulate the drilling processing of high manganese steel and calculate the continuous chip together with the drilling forces developed [8]. Klocke et al. with the same piece of software investigated the scaling effects of the cutting edge radius and the uncut chip thickness on the drilling process reactions for AISI 1045 [9]. Vijayaraghavan and Dornfeld, and Li and Shih designed solid models of drilling tools using CAD systems in order to perform further FE simulations combining both temperature and cutting force calculations [10, 11].

All these different ways to study the drilling process indicate the complexity of drilling. The geometry simulation, involves the study of both the main cutting edges and the chisel edge. The cutting action of the:

- main cutting edges of the drill have been described in detail with the classical oblique cutting theory taking into account the variable cutting speeds, inclination angles and normal rake angles along the lip. The rake angle of the cutting edges is closely related to the helix angle and decreases progressively with the helix angle from the outer corner of the drill to the chisel edge. The nominal relief angle of the drills, increases rapidly from the outer corner to the chisel edge.
- chisel edge has been described in accordance to the orthogonal cutting theory at relatively high negative rake angles and very low cutting speeds. The chisel edge extrudes into the workpiece material and contributes mainly to the thrust force and less to the torque.

The present paper aims to the calculation of the twist drill thrust force developed in conical tools with straight main cutting edges. A general purpose CAD system is used in order to produce the twist drill tool geometry and the necessary geometry for the workpieces using 3D solid modeling. A series of boolean operations using the solid models result in the creation of the incremental undeformed chips and the cut workpieces solid models. These 3D solid models are the basis for the calculation of the thrust force in a variety of tools.

The proposed methodology provides a number of advantages: a) higher accuracy of the force calculation (the forces are based on the size of the undeformed chip produced from a CAD solid model), b) calculation of the force distribution in 3D space (avoiding the classical assumptions used about even force distribution along the cutting edges), c) determination of the cutting forces separately for each cutting edge and d) possibility of different tool geometry simulation together with the desired cutting conditions. The acquisition of the 3D solid models for the tool, the undeformed chips etc. can be used for a number of downstream applications i.e. finite element simulations, tool life calculations etc.

III. The proposed methodology

Every general purposes CAD system incorporates an API (Application Programming Interface) that is able to automate all the commands that the user performs manually. This characteristic can be used in order to create applications for simulating manufacturing processes. The proposed methodology uses the API of a CAD system for the simulation of the drilling process and a new piece of software (CADRILL) is developed.

The input data of the aforementioned piece of software consist of a series of parameters derived from Galloway's mathematical description. The data (parameters) input is separated into two categories: the geometrical parameters that determine the main shape of the tool (R: tool radius in mm, W: tool web thickness in mm, p: half point angle in deg. and h: helix angle in deg.) and the manufacturing parameters that determine the detailed shape of the tool based on the conventional grinding method (g: distance of cone vertex along the x axis, s: distance of cone vertex along the y axis, θ: half cone angle). In addition, the machining parameters i.e. workpiece cutting step and feed rates are introduced (figure 1).

Galloway described the conical twist drill with straight main cutting edges using complex mathematical equations in 3D space. In the case of CADRILL, the mathematical processing is done directly from the CAD system without the direct intervention of the user. Following the input data, a set of solid models is created consisting of the twist drill tool and two separate workpieces. The information needed for the creation of both the workpieces is obtained from the user initial data and from the automatically created tool model, using geometry recognition. The first workpiece is used for the calculation of the main edges cutting forces, while the second is used for the calculation of the cutting forces due to the chisel edge. In this way, the calculation of the cutting forces is separated into two categories depending on the edge that sustains them. The first workpiece is preshaped according to the tool's point angle (in order to reach the steady state condition faster) having a hole in the middle with a diameter equal to the chisel's edge diameter. The second workpiece is a cylindrical part with a diameter equal to the chisel edge's diameter. The depth of both workpiece models is adequate for the simulation to reach the steady state condition.

The kinematics of the drilling process is introduced according to the initial data as the tool penetrates into both the workpieces. The tool is moved towards the –Z axis (feed) and at the same time is rotated around the Z axis at a constant step. In every step two Boolean operations are carried out for each of the two workpieces: a) a subtraction of the tool from the workpiece in order to obtain the shape of the remaining workpiece in each simulation step, and b) an intersection of the tool with the workpiece in order to acquire the 3D solid geometry of the undeformed chip in each simulation step. Initially the size of the undeformed chips is different in each step, but after a series of penetrations the geometry becomes constant and the steady state condition is reached. In the case of the main edge undeformed chip a simulation step of 3-4deg. is sufficient to produce accurate results, while in the case of the chisel edge a step of 5deg. was used. A series of undeformed chip geometries for different feed rates is presented in figure 2. Both the undeformed chips from the main edges and the chisel edge are presented. As the feed rate increases, the thickness of the undeformed chip increases as well, but its width remains the same. In the case of the chips due to the main edge, the external thickness has a small discrepancy compared to the internal one, while the same is not the case for the chip due to the chisel edge.

The next step is to segment the 3D models of the undeformed chips into smaller pieces in order to acquire results with increased accuracy and reduce the difference between the external thickness and the internal one in all cases. The geometrical parameters from each individual segmented 3D solid model are automatically recognized and are introduced to the thrust calculation subroutine which is based on the Kienzle-Victor method. The selection of the appropriate coefficients Ki is made based on published data [12]. When summing the primitive force components from each segmented 3D solid model the thrust force of both, the main edges and the chisel edge, can be calculated separately.

IV. The CADRILL verification

The results obtained from CADRILL were verified by performing a series of experiments on a HAAS VF1 CNC machining center with continuous speed and feed control within their boundaries. The specimen used was a CK60 plate. A Kistler type 9123 four components dynamometer was used and the signal was processed by a type 5223 multichannel signal conditioner and type 5697 data acquisition unit. The drill tools used were a D=12mm and D=16mm Bosch HSS-R (DIN 338) with 118 deg. point angle. Feed rates of 0.2, 0.3, 0.4 and 0.5 mm/rev were used together with cutting velocity values of 15 and 20m/min. In order to be able to separate the thrust force due to the main cutting edges from

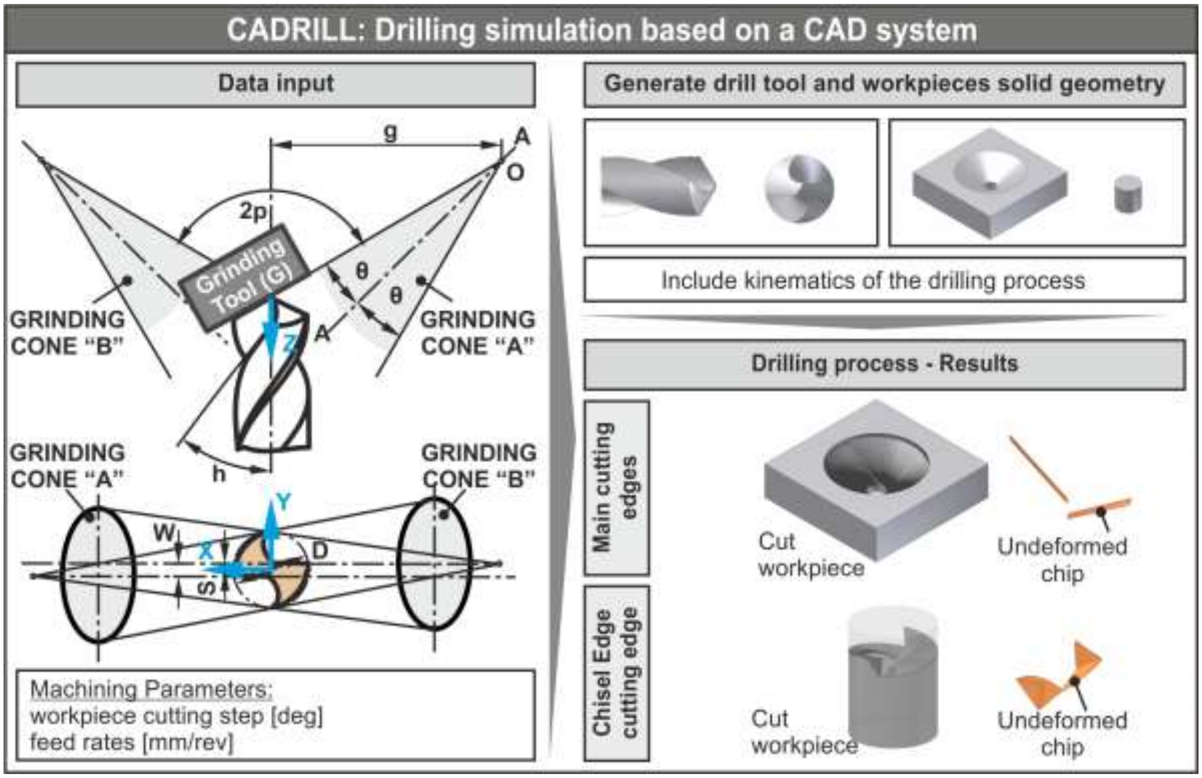

Figure 1. Drilling process simulations using a CAD system

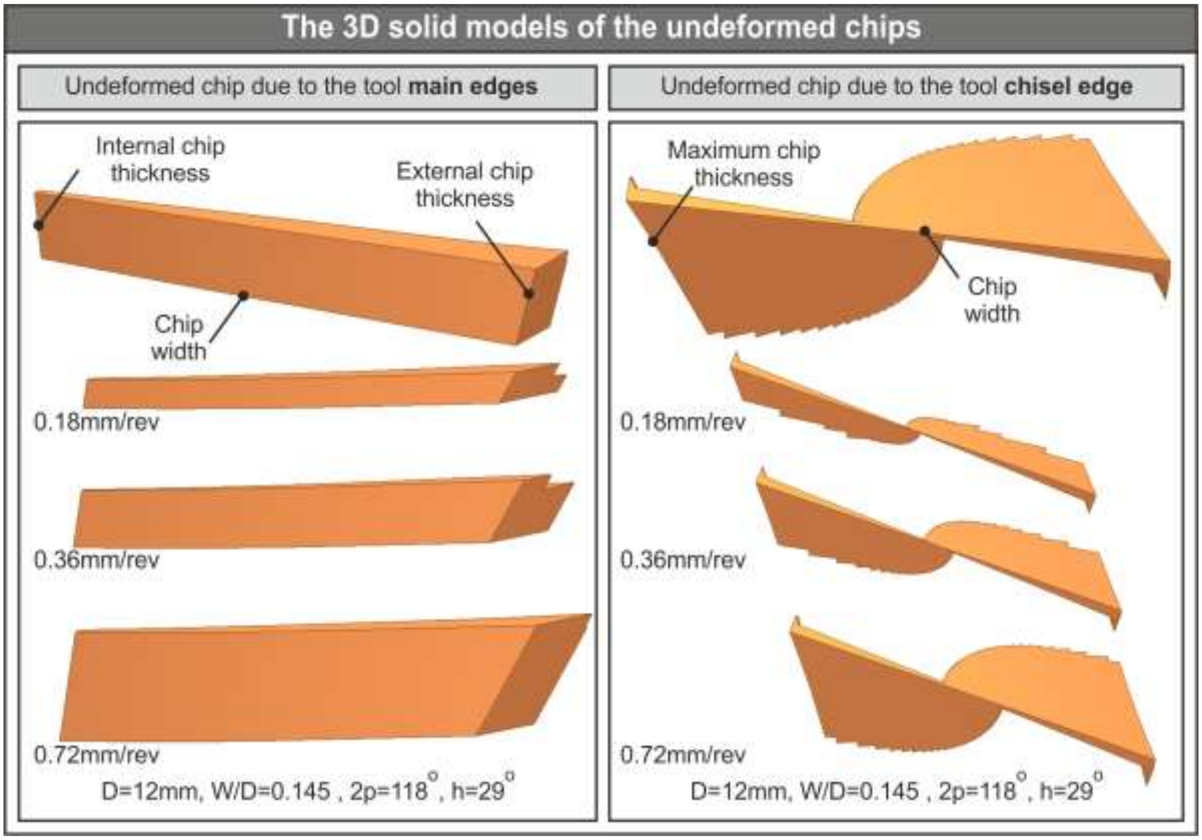

Figure 2. 3D solid models of the main edges and chisel edge undeformed chips

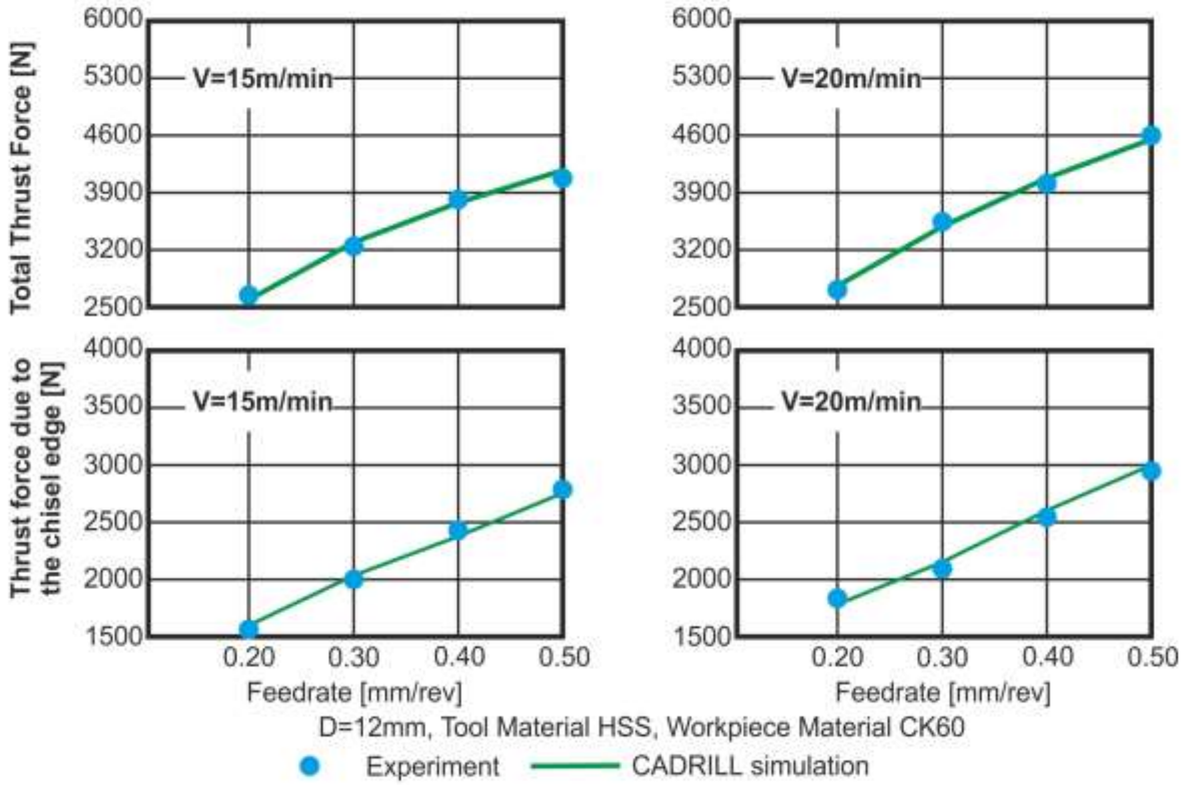

Figure 3. Evaluation of CADRILL using a D=12mm twist drill

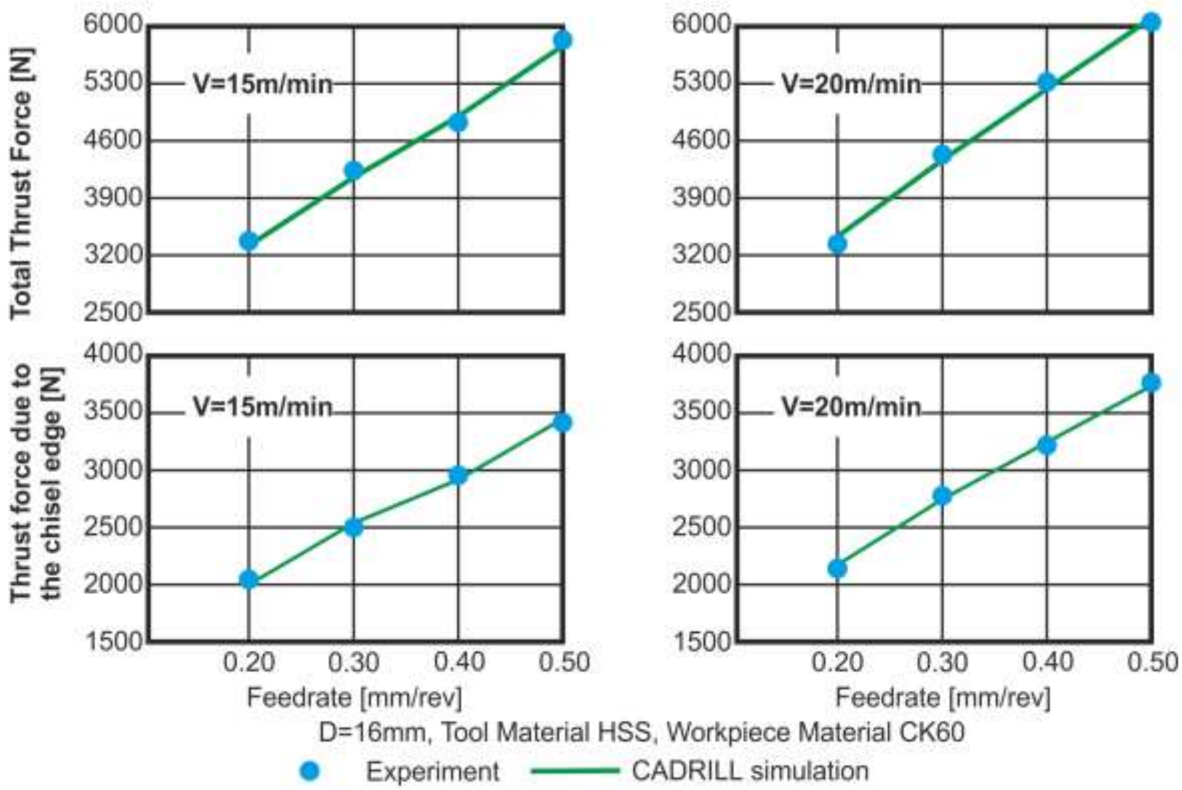

Figure 4. Evaluation of CADRILL using a D=16mm twist drill

the total thrust force, two series of experiments were conducted. The first series involved the direct drilling of the workpiece and the result was to acquire the total thrust force (due to the main edges and the chisel edge). In the second series, the workpiece was preshaped with an additional hole in the middle, with diameter equal to the chisel edge of the tool used. This way the effect of only the main edges was measured and the direct comparison of the simulated and acquired results were possible.

Figure 3 presents the thrust force results for a tool with a diameter of 12mm. Different feed rates were used and both the total thrust force and the thrust force due to the chisel edge were simulated and experimentally verified. As expected, when the feed increases both forces increase as well. In addition to that, when the cutting speed increases, a smaller but significant increase in both the forces is depicted. Similar results are obtained for the tool with a diameter of 16mm (figure 4). All the forces in both cutting speeds are substantially increased, when the diameter is increased. In all cases the results derived from CADRILL and experiments are very close, and prove the validity of the proposed methodology. Additionally, evidence is provided that the thrust force due to the chisel edge equals approximately the two thirds of the total thrust force and this is true for both the twist drills used for the verification of the simulation.

V. Conclusions

During the last few years, CAD systems have become widely available for use in industry. They have improved the productivity and the performance of a series of processes. Most of the times, they incorporate an API which can be used for automating processes and generate software applications for manufacturing.

CADRILL is such an application and simulates the drilling process using 3D solid models of the twist tools and workpieces. It calculates the produced thrust forces and separates the action of the main cutting edges and the chisel edge. The simulation is based on the accurate calculation of the undeformed chips produced, and the derived data have been successfully confirmed with a series of experiments. Two twist drill tools with diameters of 12mm and 16mm were used, together with the selection of four feed rates (0.2, 0.3, 0.4, 0.5 in mm/rev) and two cutting speeds (15 and 20 in m/min). It is expected more combinations of tool and workpiece materials and cutting conditions to be available as a tool to the manufacturing industry.

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References

[1] D. Galloway “Some experiments on the influence of various factors on drill performance”, Trans. A.S.M.E., Vol. 79, pp. 191-231, 1957.

[2] W. Tsai and S.M. Wu “A mathematical drill point design and grinding”, Journal of Engineering for Industry, Vol. 101, pp.333–340, 1979.

[3] W. Tsai and S.M. Wu “Computer analysis of drill point geometry”, Int. J. Mach. Tool Des. Res, Vol 19, pp. 95-108, 1979.

[4] W. Tsai and S.M. Wu “Measurement and control of the drill point grinding process”, Int. J. Mach. Tool Des. Res, Vol 19, pp. 109-120, 1979.

[5] K. Sambhav, P. Tandon and S.G. Dhande “Geometric modeling and validation of twist drills with a generic point profile”, Applied Mathematical Modelling, Vol. 36, pp.2384-2403, 2012.

[6] E. Bagci and B. Ozcelik “Finite element and experimental investigation of temperature changes on a twist drill in sequential dry drilling”, International Journal of Advanced Manufacturing Technology, Vol. 28, pp.680-687, 2006.

[7] R. Li and A. Shih “Finite element modelling of high throughput drilling of Ti6Al4V”, Transactions of NAMRI/SME, Vol. 35, pp.73-80, 2007.

[8] X. Li and Y. Liang “Finite element simulation and experiment study of high manganese steel drilling”, Second International Conference on Computer Modeling and Simulation – IEEE, pp.54-58, 2010.

[9] F. Klocke, D. Lung, K. Gerschwiler and M. Abouridouane “Scaling effects of the cutting edge rounding on the minimum uncut chip thickness and 3D FE modelling in drilling”, 10th CIRP International Workshop on modelling of Machining Operations, August 2007.

[10] A. Vijayaraghavan and D. Dornfeld “Automated drill modeling for drilling process simulation”, Journal of Computing and Information Science in Engineering, Vol. 7, pp.276-283, 2007.

[11] R. Li and A.J. Shih “Tool temperature in titanium drilling”. Transactions of the ASME, Vol. 129, pp.740-749, 2007.

[12] O. Kienzle and H. Victor “Spezifische Shnittkraefte bei der Metall-bearbeitung”, Werkstattstehnik und Maschinenbau Bd.47, H.5., 1957.

About the Author (s):

Dr P. Kyratsis is an Assistant Professor in the Dept. of Mechanical and Industrial Design Engineering, TEI of W. Macedonia, Greece. His main research interests include manufacturing, CAD/CAM/CAE, product design.

Associate Prof. K. Kakoulis works for the Dept. of Mechanical and Industrial Design Engineering, TEI of W. Macedonia, Greece. His main research interests include design and analysis of algorithms, information visualization, geometric modeling.

Assistant Professor E. Maravelakis works for the Dept. of Natural Resources & Environment, TEI of Crete, Greece. He is heavily involved in CAD/CAM, reverse engineering, innovation and product design research activities and projects.