# Parametric modelling and simulation on oblique cutting based on MSC.Marc

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**Abstract**

The finite element simulation of oblique cutting is a complex and professional process. It is necessary to build a system to construct a model in order to obtain simulation values more conveniently and rapidly. The key techniques of 3-D parametric modelling with MSC.Marc software metal oblique cutting simulation was presented in this investigate. The modelling rule based on the process was carried out. The system, designed using C++ Builder, can access data, which includes the geometrical angles and dimensions of tool, the sizes of workpiece, the relative position between tool and workpiece. Meanwhile their properties and cutting conditions, etc. were stored. The procedure file modelling in the MSC.Marc environment automatically is generated by the program. So the parametric modelling of simulation is completed by calling the procedure file. Further, an example was given and the simulation model was also verified. Therefore, the parametric modelling is a kind of effective way for metal cutting simulation.

*Keywords:* oblique cutting, numerical simulation, parametric modelling, interface design

## 1 Introduction

Metal cutting is one of the most common machining methods in manufacture industry. The pursuit of corporations is to obtain high quality, and great efficiency. Studying metal machining mechanism is the main approach to achieve this target [1-4]. However, the machining process of metal cutting is quite complex, relating to physics, mechanics, elastic-plastic theory, metal material, thermology and superficial science (tribology) and so on. There are three ways to study metal cutting: analytics, experiment/analytics and numerical method. Analytics method mainly includes slab stress method, slip-lines field method and upper bound method, which are a part of classical solution in plasticity mechanics; experiment/analytics, i.e. the integration of experiment and analytics include similarity theory and inspection plastic method. The experimental methods in common is used to study the metal cutting process involving the side square deformation observation method, high-speed photography method, scanning electronic microscopy, photo-elastic (photo-plasticity) method and X-ray method. Numerical methods include finite-element method, finite difference method and boundary element method. Traditional analytics are quite difficult when analysing and studying cutting mechanism quantitatively. It takes a long time and is tedious to applying experiment/analytics to obtain cutting forces and temperatures values. With the development of the technology of computer software and hardware and the theories related to metal machining becoming more and more perfect, numerical method is used extensively, especially finite element method. So far, there is much research on numerical simulation of metal cutting overseas. However, the work on this aspect is limited, and mostly focused on orthogonal cutting [5-7].

It is the trend that finite element numerical simulation will be helpful in knowing about metal machining situation. Whereas modelling is a complex procedure, parametric modelling of the program driven method was considered in this study, and some techniques will be discussed.

## 2 Finite element modelling

During the process of cutting, for example: oblique cutting its edge is out of the vertical of cutting velocity. Thus, cutters whose inclination angle is not zero are oblique cutting. Figure 1 shows 3-D finite element model of oblique cutting.

The contents of finite element modelling of cutting process include geometric modelling and meshing, boundary conditions, material parameters, geometric parameters, initial conditions, contact conditions, load cases etc.

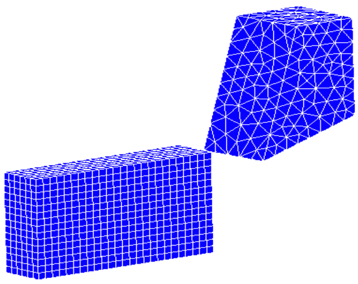

FIGURE 1 The model of oblique cutting

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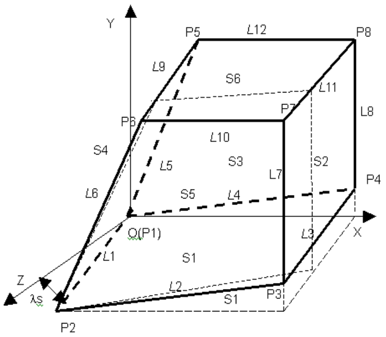


FIGURE 2 Model of cutting tool

## 2.1 PARAMETRIC MODELING OF TOOL

Based on the physical model and characteristics of finite element analysis software, B-rep (Boundary representation) is employed. The method can express two kinds of information: a geometric one and a topological one. Geometrical data reflects the dimensions and the position of objects. Topological information describes the relative position. The solid model of tool is presented in Figure 2 and Cutting plane and normal sectional plane of the tool are seen in Figure 3. Topological information and geometric information of tool are shown in Figure 4.

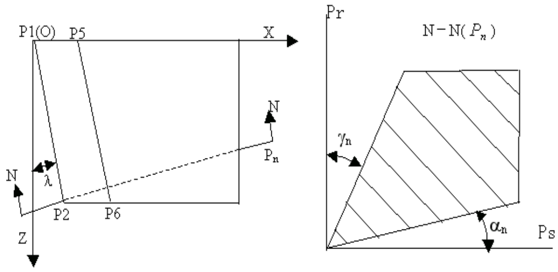


FIGURE 3 Cutting plane and normal sectional plane of *t* tool

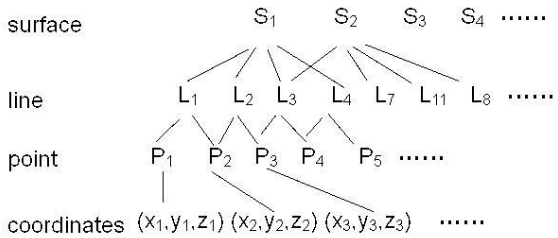


FIGURE 4 Topological and geometric information of tool

By inference, all points' coordinates of cutter are seen in Table 1.

Parametric modelling is a key technique that affects the utility on numeric simulation. Through generating a procedure file, it is possible to do it quickly and conveniently.

By inference, all points' coordinates of tool are seen in Table 1.

TABLE 1 The coordinates of model on tool and workpiece

| Point | *X*-coordinate | *Y*-coordinate | *Z*-coordinate |
|---|---|---|---|
| $P_1$ | 0 | 0 | 0 |
| $P_2$ | $l_1 \times \sin\lambda_s$ | 0 | $l_1 \times \cos\lambda_s$ |
| $P_3$ | $l_4 \times \cos\alpha_0$ | $(l_4 \times \cos\alpha_0 - l_1 \times \sin\lambda_s) \times \mathrm{tg}\alpha_0$ | $l_1 \times \cos\lambda_s$ |
| $P_4$ | $l_4 \times \cos\alpha_0$ | $l_4 \times \sin\alpha_0$ | 0 |
| $P_5$ | $l_5 \times \sin\gamma_0$ | $l_5 \times \cos\gamma_0$ | 0 |
| $P_6$ | $l_5 \times \sin\gamma_0 + l_1 \times \sin\lambda_s$ | $l_5 \times \cos\gamma_0$ | $l_1 \times \cos\lambda_s$ |
| $P_7$ | $l_4 \times \cos\alpha_0$ | $l_5 \times \cos\gamma_0$ | $l_1 \times \cos\lambda_s$ |
| $P_8$ | $l_4 \times \cos\alpha_0$ | $l_5 \times \cos\gamma_0$ | 0 |
| $W_1$ | $-s - l$ | $a_p - h$ | $b$ |
| $W_2$ | $-s$ | $a_p - h$ | $b$ |
| $W_3$ | $-s$ | $a_p$ | $b$ |
| $W_4$ | $-s - l$ | $a_p$ | $b$ |

Where $l_i$ is the length of every line, $i$=1, 2,…, 12. $\lambda_s$ is the inclination angle. $\gamma_0$ is the rake angle and $\alpha_0$ is the flank angle. *S* is the distance between the work and the cutting edge. *l* is the length of the work along the direction of cutting edge. H is the height of the work. $a_p$ is the depth of cut. *b* is the distance between tool-tip and the side of the work along the cutting edge direction.

## 2.2 PARAMETRIC MODELING OF WORK

The work model is constructed in scanning method (Figure 5). Top view and side view of the model of work are seen in Figure 6. Its benchmark is defined by cutting tool. Because the work is a cuboid, the solid work is obtained through its surface that consist of four vertexes ($W_1$, $W_2$, $W_3$ and $W_4$) in the *XOZ* sweeping along the direction of *Z*-axis. The coordinates of the four points on the work are given in Table 1.

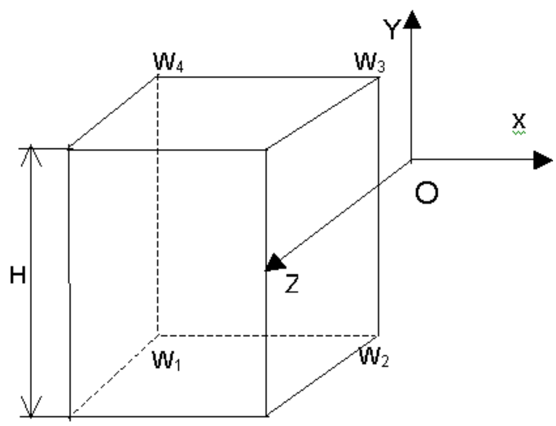


FIGURE 5 Model of work

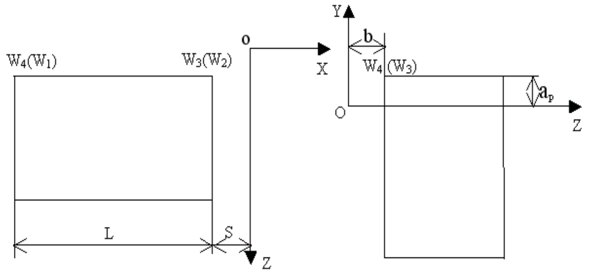


FIGURE 6 Top view and side view of the model of work

A finite element model of a cutter and a work generated and mesh automatically in MSC.Marc by designing interface.

## 2.3 MATERIAL MODEL

During a practical cutting process, the material of work results in elastic-plastic strain under the condition of high temperature, large strain and large strain ratio. Johnson-Cook model describes material yielding flow properties of the cutting region more accurately. The Johnson-Cook equation is described as follows [1]:

$$\bar{\sigma}=\left[A+B(\bar{\varepsilon})^{n}\right]\left[1+C\ln\left(\frac{\bar{\varepsilon}}{\bar{\varepsilon}_0}\right)\right]\left[1-\left(\frac{T-T_{room}}{T_{melt}-T_{room}}\right)^{m}\right], \quad (1)$$

where $A$, $B$, $n$, $C$ and $m$ are the parameters determined by a material itself. $T_{melt}$ is melting temperature. $T_{room}$ is the room temperature.

## 2.4 FRICTION MODEL BETWEEN TOOL AND CHIP

There are two explicit areas on the rake surface: slip region and glue region. On the basis of research, constant coefficient friction is applied in slip region and constant friction stress is used in glue one. The friction stress is written as:

$$f=\begin{cases}\mu\sigma_n & \sigma_f=\mu\sigma_n \\ k & \sigma_f=k\end{cases}, \quad (2)$$

where $\sigma_n$ is normal stress. $\mu$ is friction coefficient and $k$ is shear stress.

## 2.5 THE CRITERION OF CHIP SEPARATION

During the simulation, there are criterions that make the chip separate from work and rake face. They are divided into geometric criterion and physical criterion. The geometric criterion decides the separation through the changes of geometric dimension of deformable body. The physical one is used to identify whether magnitude of physical quantity causes critical value or not.

In fact, chips are separated by setting a minimum force or stress of the nodes as threshold.

## 2.6 EQUATION OF HEAT CONDUCTION

Because the system consists of work, chip and tool generates heat continuously, the first and the second deformation zone of the work go through plastic and elastic deformation. Besides, the rake surface of the tool has severe friction [8].

Equation of the heat conduction in 3-D unsteady-state temperature field (take into account variable thermal conductivity) is defined as follows:

$$\rho c\frac{\partial T}{\partial t}=K\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)+ \frac{dK}{dT}\left[\left(\frac{\partial T}{\partial x}\right)^2+\left(\frac{\partial T}{\partial y}\right)^2+\left(\frac{\partial T}{\partial z}\right)^2\right]- \rho c\left(w_x\frac{\partial T}{\partial x}+w_y\frac{\partial T}{\partial y}+w_z\frac{\partial T}{\partial z}\right)+q^*, \quad (3)$$

where $K$ represents the thermo conductivity coefficient and $T$ is temperature. ρ is the material density and c is thermal capacity. $X$, $Y$ and $Z$ are cartesian coordinate system; $w_x$, $w_y$ and $w_z$ are velocity component of kinematic heat-source in $x$, $y$ and $z$-axis. $q^*$ is heat generation rate per unit volume:

$$q^*=W_h\bar{\sigma}\frac{\dot{\bar{\varepsilon}}}{J}, \quad (4)$$

where $W_h$ is the ratio that plastic deformation work turn into heat energy. $\bar{\sigma}$ is the equivalence stress. $\dot{\bar{\varepsilon}}$ is the equivalence strain ratio. $J$ is coefficient of thermal equivalent of work. As the amount of radiant heat is little, it is ignored.

## 3 Key techniques

The concept data mode of machining condition is shown Figure 7. The information mentioned above is stored into every table respectively, from which a model of milling process is built by knowledge acquisition machine and explanation machine. The component table includes its geometric and process information based on STEP (standard for the exchange of product model data) APP244 (application protocol). The component material table has physical and chemical properties, and mechanical behaviours. The cutting-tool table describes its dimensions, angles and material). The machine tool table provide with its property parameters and machining parameters. And other tables indicate other modelling data separately.

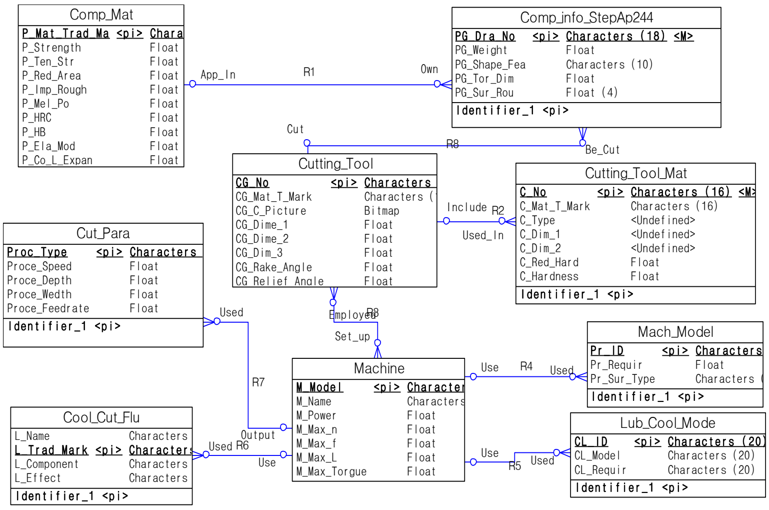


FIGURE 7 The concept data mode of machining condition

## 3.1 THE INTERFACE DESIGN OF PARAMETRIC MODELING

### *3.1.1 The interface design between C++Builder and database*

Database module and database engine provided by C++ Builder or ADO (Active Data Object) were used to access data. The tables whose type is DBF (Database File) and BDE (Borland Database Engine) were used, while parameters about BDE were set, such as path, type and language drive.

### *3.1.2 The interface file of parametric modelling in Marc*

The system's knowledge based on rule was established according to MSC.Marc software character. And procedure files were written using C++ Builder code according to the rule.

Based on the solid model of cutting tool, and the topology and geometry information of the tool, its geometry information such as points, line and surface were written in program line-by-line, and then meshed automatically. With regard to work with a rectangular, a surface consists of four point first and then swept towards *Z*-axis to form work model. A work model was also meshed. The modelling procedure mentioned above is written in procedure file. While relative position between tool and work, material model, friction model between tool and chip, properties of cutter and work, cutting conditions, all set about finite element simulation and so on, are written into the program.

The generating procedure file can be operated according to specified format. The modelling process becomes easy. The block diagram of modelling process is shown in Figure 8. The structure of procedure file is seen in Figure 9.

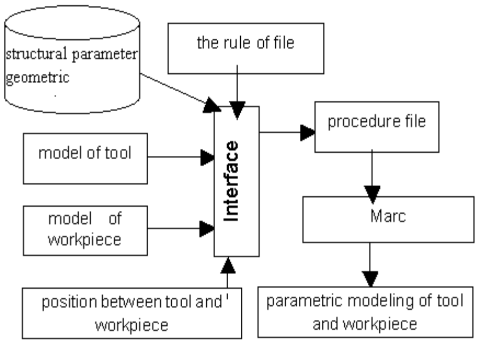


FIGURE 8 Parametric modelling process

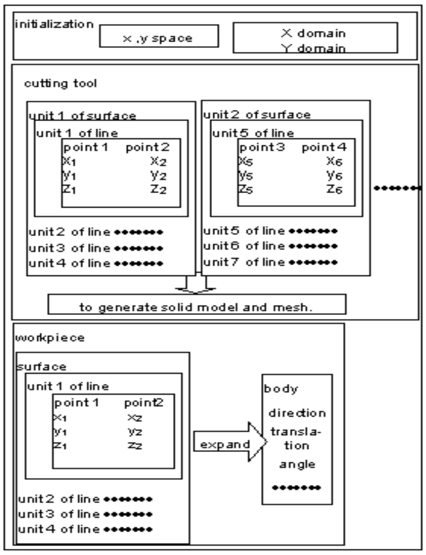


FIGURE 9 Structure of procedure file

## 3.2 REMESHING TECHNIQUE

With regard to the large deformation, an Updated Lagrange analytical method were adopted. Because excessive deformation of mesh makes successor analysis restrictive, remeshing function was conducted, and original state variable could be mapped.

It is requirement to combine the contact penetration with increment and re-meshing when simulating cutting process. Then the set of chip separating from work can be performed.

### 3.3 MESH ADAPTIVE TECHNIQUE

In selected elements, these elements will be re-meshed in incremental step when they disobey given error criterion. The average of strain energy and contact adaptive criterion were employed. The density of mesh can be adjusted automatically, and computation efficiency of the complex problem and precision will be improved.

## 4 Result of modelling

Figure 10 shows the interface of oblique cutting modelling. Through the interface, operator can finish modelling (Figure 1). The Equivalent Mises stress distribution of simulation is shown in Figure 11.

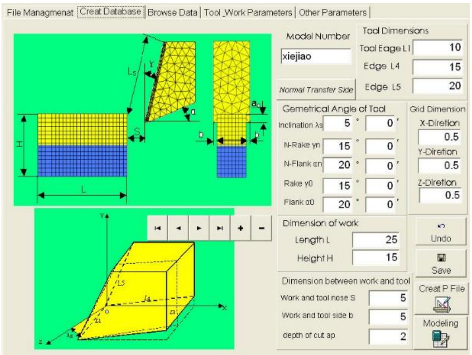

FIGURE 10 The interface of oblique cutting modelling

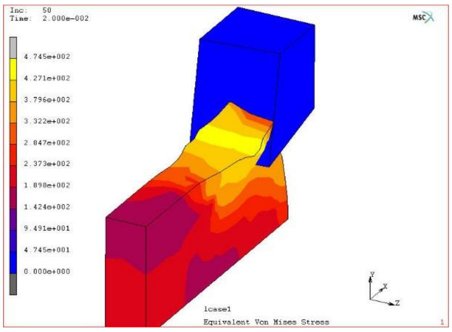

FIGURE 11 Equivalent Mises stress distribution

## 5 Conclusions

The techniques of parametric modelling, which include database, C++ Builder programming, remeshing and mesh adaptive, were discussed. A model of the oblique cutting process was constructed and employed to simulate for the sake of prediction the change of cutting force and temperature, etc. A running example test and verify the parametric modelling. The intelligent parametric modelling will be further investigated to perform a lot of simulation condition. Parametric modelling method will also be applied to simulate in other aspects such as the quality of machined surface or tool wear during machining process.

## 6. Acknowledgements

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