Modeling of Tool Wearing With Artificial Neural Network in 3D Virtual Manufacturing System

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Abstract

In this study, effect of cutting tool wearing on the workpiece has been reviewed in three dimensional (3D) virtual machining software environments. Cutting tool wearing was obtained by artificial neural network method. In virtual environment, polygon based modeling technique was utilized to define the interaction of workpiece and cutting tool while forward propagation technique was utilized for the information of cutting tool wearing. Hardness of the material to be cut, type of the used cutting tool and amount of wearing took place on the cutting tool according to cutting parameters were reflected to 3D cutting tool model, and the amount of chip remained on the final workpiece was obtained. When experimental and Artificial Neural Network (ANN) results were compared, it was revealed that the designed model was successfully created.

Key words: Tool geometry, Virtual Machining, Artificial Neural Network

Özet

Bu çalışmada, yapay sinir ağı tekniği ile elde edilen kesici takım aşınma modelinin üç boyutlu (3B) sanal işleme yazılımında iş parçasına etkisi incelenmiştir. Sanal ortamda iş parçası ve kesici takımın etkileşimini tanımlamak için poligon tabanlı modelleme tekniğinden, kesici takım aşınma bilgisi için geri yayılım tekniğinden faydalanılmıştır. Kesilecek malzemenin sertliği, kullanılan kesici takımın cinsi ve kesme parametrelerine göre kesici takım üzerinde meydana gelen aşınma miktarı 3B kesici takım modeline yansıtılmış ve nihai iş parçası üzerinde kalan talaş miktarı elde edilmiştir. Deneysel sonuçlarla YSA sonuçları karşılaştırıldığında, tasarlanan modelin başarılı bir şekilde oluşturulduğu ortaya konmuştur.

Anahtar kelimeler: Takım geometrisi, Sanal imalat, Yapay sinir ağları

1. Introduction

Turning operation is one of the most important production processes in machining industry. Quality of the pieces obtained as result of turning is a factor that affects total product quality. Thus, it is obligatory to increase quality level for these pieces [1]. In every machining operation, main factors affecting the cost and quality are workpiece and cutting tool interaction model. During machining, cutting tool is exposed to loads which are called cutting forces. Cutting forces result from plastic deformation which occurs in primary and secondary deformation zones of the material, and due to frictions developed in interfaces of tool chip and tool workpiece.

In machining experiments, two different methods are used that are orthogonal and oblique cutting. Since oblique cutting method is 3D, it has a more complex geometry compared to

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orthogonal cutting operation. Thus, the orthogonal method in which operation control can be made easier and more effective in experimental studies, have less number of parameters and in which mechanical behavior can be reviewed as 2D, is more preferred [2]. During machining, there are various factors affecting the cutting force. Cutting speed, feed rate, tool geometry, operation type, workpiece and tool material are among important factors affecting the cutting force. Among these factors, cutting tool geometry is an important factor affecting each of the issues such as chip formation, surface roughness and tool wearing, along its effect on cutting forces [3].

In recent years, a lot of different methods were developed in order to analyses machining process. Rapid developments in computer technology and increase in computerized graphic applications allowed complex numerical methodic analyses to be made in computer environment. Particularly, the finite elements method (FEM) became to attract an increasing attention today. For the analysis of machining processes in turning operations, finite elements methods which are based on Eulerian and Lagrangian algorithm methods were developed [4].

Machining operation includes non-linear explicit calculations and it is hard to transfer too many experimental data into computer environment. Moreover; since experimental studies take long time, are inconvenient and expensive; this makes manufacture process difficult to validate. Due to such reasons, process prediction methods were developed which are based on goal-oriented experimental data and statistical data analysis. Four methods used in order to predict tool wearing in the industry are as follows;

- Multiple regression analysis,
- Mathematical modeling,
- Fuzzy set based techniques,
- Artificial Neural Network (ANN) modeling.

Modeling of cutting tool wearing mechanism is a complex process which is essentially based on machining operation. Therefore, it is quite hard to analytically find the wearing value. Based upon the current experimental wearing data, it is quite easy to make the process analyses by ANN methods. In the studies conducted accordingly, it has been observed that experimental data and ANN data gave similar results. Du et al. have observed the chipping and wearing of tool and chip formation by using ANN method during turning operation. In the study, multiple sensor systems which included power sensor, force sensor and vibration sensor were used for experimental data, and this indicated 90 percent accuracy [5]. In another study, Neşeli et al. aimed to predict the surface roughness in turning operation by ANN approach. As the input parameter; cutting tool tip radius, approach angel and rake angle were defined. For the output parameter (Ra), surface roughness was predicted. The obtained data were compared to experimental results and identified that they gave similar results [1].

In manufacturing systems, virtual manufacturing systems were developed for error check. With these systems, tool movements and final status of workpiece can be displayed 3D in computer environment. Virtual manufacturing systems have made progress with two different approaches as physical and model based. Machining analyses performed by finite elements method depend on physics based modeling principal. But the Computer Aided Manufacturing (CAM) software used in Industry is developed by model based approaches, due to their advantages.

In this study, apart from CAM software, the effect of cutting tool wearing model obtained by ANN technique to workpiece was reviewed in 3D virtual machining software environment. In order to define the interaction of workpiece and cutting tool in virtual environment, polygon based modeling technique was utilized and to define the information of cutting tool wearing, back propagation technique was utilized. Workpiece material, type of cutting tool and amount of wearing took place on the cutting tool according to cutting parameters were reflected to 3D cutting tool model, and the amount of chip remained on the final workpiece was obtained. MATLAB was utilized in creating the wearing model while OpenGL graphic programming language was utilized in preparing of 3D object models.

2. Experimental Studies

Machinability experiments were performed by turning the SAE 1030 85HRC stainless steel material. Chemical components of this material are provided in Table 1. Machining experiments on the cylindrical workpiece material were performed by using Goodway GA-280L CNC turning lathe. Workpiece materials are 150 mm in length and 40 mm in diameter. During the experiments, coolant was not used. As the cutting tool, IC8250 and IC9250 tips of Sandwick Company were preferred. These tools were recommended by the producer company to machine the stainless steels. These cutting tools were connected mechanically in a rigid manner with 75° entering angle to DDJNR 2525 M-15 tool holder. The used cutting speeds were preferred as 130, 140 and 150 m/min Feed rate was determined as 0.15, 0.20 and 0.30 mm/rev and depth of cut was determined as 2.5 mm. Experiment parameters were prepared according to ISO 3685 standard to the extent possible.

Table 1. Chemical Component of the Material

	C	S	P	Mn	Ni	Mo	Cu
AISI 1030	0.30	0.028	0.012	0.68	0.09	5.00	0.29

Table 2. Machining parameters

	Parameters
Machine tool	Good Way GA-280L
Cutting Tool Material	IC8250 and IC9250
Work piece Material	SAE 1030 85 HRC
Cutting Speed	130, 140, 150 m/min.
Feed Rate	0.15, 0.20, 0.30 mm/min.
Depth of Cut	2.5 mm
Flank Wear	VB

Worn cutting tips were observed in a JEOL JSM 6360 LV type scanning electron microscope (SEM). In Figure 1, wearings are visible on SEM photographs of the cutting tool used for machining of the SAE 1030 85HRC stainless steel material, which were shot from the rake face. Wearing took place mainly in three regions; the region where cutting tool is in contact with the unmachined workpiece surface; the region where cutting tool drifted away from the workpiece surface and; the nose region.

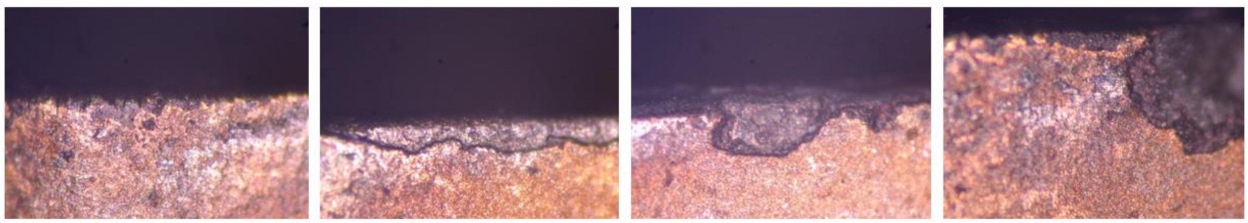

Figure 1. Flank wear according to machining time x50 a) 5m. b) 10m. c) 15m. d) 20m.

It is seen from the SEM photographs that wearing are in shapes of chipping. Chippings can be better seen in the SEM photograph, which was shot with a larger close up on the region where cutting tool drifted away from the new formed workpiece. Chippings which take place here are result of adhesive wearing mechanism.

Table 3. Machining parameters

Cutting Tool	Feed Rate	Cutting Speed		
		130	**140**	**150**
IC 8250	0.15	0.060	0.055	0.050
	0.20	0.055	0.045	0.040
	0.30	0.060	0.050	0.045
IC 9250	0.15	0.070	0.065	0.055
	0.20	0.065	0.060	0.045
	0.30	0.075	0.070	0.060

As the cutting speed increased, a reduction was observed in flank wear due to decrease of built-up edge (BUE) on the tool. Accordingly, it was identified that VB flank wear decreased indirectly as the cutting speed increased. Flank wear decreased as feed rate was raised from 0.15 mm/rev to 0.2 mm/rev while an increase was observed in VB value as it was raised to 0.3 mm/rev. It was observed that the least flank wear was at 150 m/min cutting speed and 0.2 mm/rev feed rate. In Table 3, the flank wear results which took place in different cutting parameters were stated numerically.

3. 3D Cutting Tool and Workpiece Geometry

In turning operation, the cutting tool and workpiece can be considered as vector based polygon model. In this approach base, polygon cropping technique is applied to both pieces in order to obtain the desired geometry during simulation. As result of polygon interaction with each other, dynamic piece geometry is activated and the final 3D model of the piece to be machined is produced with this method.

In polygon modeling technique, cutting tool and workpiece creating structure are very close to each other. Basically, two differences are observed. The first one is that instead of length and diameter coordinates in the workpiece, cutting tool limit coordinate information are needed. And the second one is, while rotational sweeping operation is applied in forming of workpiece 3D model, linear sweeping operation is applied for cutting tool model. Cutting tool geometry is built up parametrically as different from workpiece in terms of industrial use. According to ISO 13339 standard; tool type, inner diameter, length of cutting edge and tip curve information are defined as variable parameter while limit coordinates are defined parametrically.

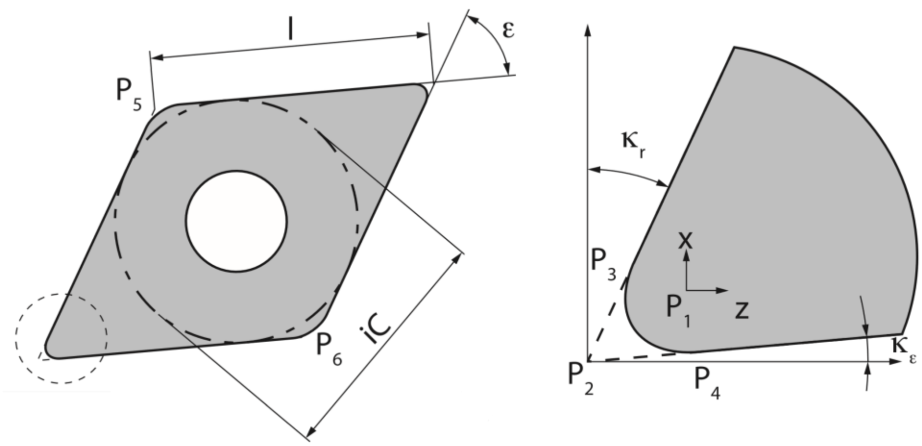

Figure 2. Rhomboid cutting tip parameters [6]

In practice, tool geometry is rhombus. These types of cutting tools are widely used in turning operations. Parametrical rhomboid tool limit terms:

$$P_1 = P(0,0)$$
$$P_2 = P\left(cos\left(\frac{3\pi}{2} - \frac{\varepsilon}{2} - K_r\right)\frac{r_\varepsilon}{sin\left(\frac{\varepsilon}{2}\right)}, sin\left(\frac{3\pi}{2} - \frac{\varepsilon}{2} - K_r\right)\frac{r_\varepsilon}{sin\left(\frac{\varepsilon}{2}\right)}\right)$$
$$P_3 = P(cos(\pi - K_r)r_\varepsilon, sin(\pi - K_r)r_\varepsilon)$$
$$P_4 = P\left(cos\left(K_\varepsilon - \frac{\pi}{2}\right)r_\varepsilon, sin\left(K_\varepsilon - \frac{\pi}{2}\right)r_\varepsilon\right)$$
$$P_5 = P\left(P_{2x} + cos\left(\frac{\pi}{2} - K_r\right)L, P_{2y} + sin\left(\frac{\pi}{2} - K_r\right)\ L\ \right)$$
$$P_6 = P\left(P_{2x} + cos\left(\frac{\pi}{2} - K_r - \varepsilon\right)L, P_{2y} + sin\left(\frac{\pi}{2} - K_r - \varepsilon\right)L\right)$$

Here, the cutting edge shows central coordinate while its other values state the corner coordinates of cutting tool. Tip curve, side length 1 and tip angle variables are entered by the user, and the above equations are calculated by using these means.

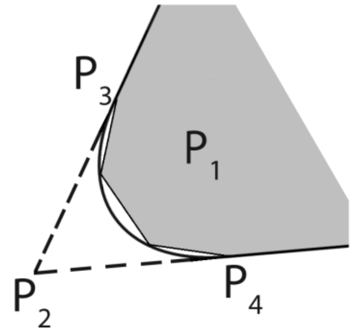

Figure 3. Cutting curve parameters [6]

Since cutting tool shall be drawn by the help of lines, tip curve is modeled by small pieces of line. In 3D transformation of cutting tool polygon geometry prepared on 2D plane, linear sweeping operation is applied. This operation is carried out by reconstruction of polygon lines that constitute the cutting tool in a stated vector, and filling their gaps by using netting method.

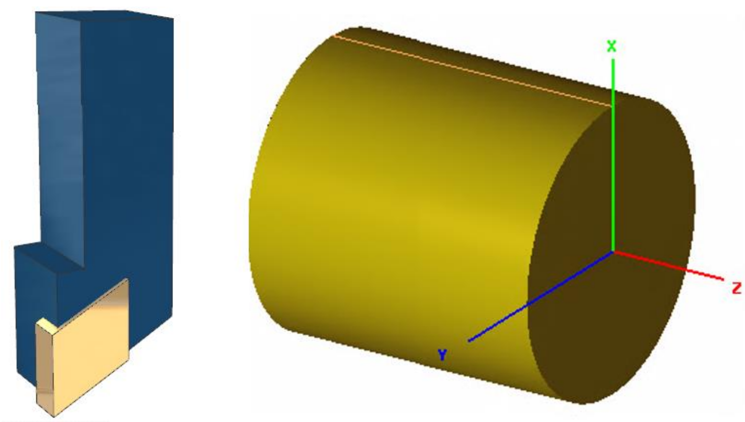

Figure 4. The developed cutting edge and workpiece 3D model

Lines forming the polygon geometry to be swept are shifted one by one as much as the distance determined in the Y plane. The rectangular areas formed as result of shifting are divided into two by intersection line according to triangular network netting methodology. This operation is expressed as linear sweeping. When sweeping operation is applied for all the edge lines of the polygon and mathematical operation is carried out, final swept polygon structure is obtained. Similar process is applied for workpiece 3D model as well.

4. Application of Tool Wearing In Virtual Environment

In order to determine the wearing status of cutting tool, the performed experimental data were performed. Artificial neural network model was installed in MATLAB environment with the obtained wearing measurements. Since the abundance of variable data of cutting tool wearing information shall increase the number of iteration, some variables were taken constant. The obtained wearing data sets were transferred to virtual machining system According to cutting parameters received from CNC code information and workpiece cutting tool material information, the cutting tool 2D polygon geometry is instantly updated and amount of deviation in dimensions of the workpiece is identified in virtual environment.

Based on flow direction of the sign at artificial neural network, there are two types of network models which are feed forward or feedback/recurrent networks. In this study, feed forward network structure was used. In this network, information only moves in forward direction and towards output layer. The system is memory less. This network structure is also called static network. In the figure, multilayer feed forward network structure which is developed in scope of this study is present. As seen in the figure, signals are always carried in forward direction. Weights of feed forward connections can be changed during training, but weights of feedback connections cannot be changed, they remain constant. For learning network, there are 3 neuron structures available in input layer while 5 in hidden layer and 1 in output layer. The set up algorithm was compiled in MATLAB environment.

In order to minimize the errors likely to occur in ANN, training algorithms are used. Training algorithms minimize the error value by adjusting the weights in network. Sum of a mean square error is calculated by the following equation;

$$E(w) = \frac{1}{n}\sum_{\varepsilon,i}(ei^{\varepsilon})^2 = \frac{1}{n}\sum_{\varepsilon,i}(di^{\varepsilon} - yi^{\varepsilon})^2$$

It is the intended output value and the value obtained from network output. Every weight is adjusted by the following equation:

$$w^{(k+1)} = w^{(k)} + \Delta w^{(k)}$$

Reducing $E(w)$ as quick as possible depends on the training algorithm, calculation of which is to be used. Another method used in applications is the back propagation algorithm. In back propagation network, errors are propagated backwards by the derivative of forward feed transfer function, through the connections used in forward feed mechanism. The standard back propagation algorithm has disadvantages such as long calculation period and convergence risk in local minimum. The Levenberg – Marquart algorithm, one of the high performance back propagation training algorithms that improves performance by using different optimization techniques, was used in scope of this study to train ANN. Levenberg – Marquart is a minimum square calculation method, which was basically established on closest neighborhood. This algorithm consists of the best features of Gauss-Newton and Gradient- Descent algorithms, and removes the limitations of these two methods. Generally, this method is not affected from slow convergence risk. The Levenberg – Marquart algorithm, which is a combination of Gauss-Newton algorithm, is more effective in optimization problems compared to gradient descent algorithm. And it is faster.

To form a neural network model; way of connection, addition and activation functions used by processor elements, learning method, learning rule and its algorithm should be identified. Model is designed according to available data. Success of the installed model is directly associated with the right formation of model's architecture. For that, ANN designer should decide the following with respect to structure and operation of the network:

- Selection of network architecture and determination of its structural characteristics,
- Determination of characteristic features of functions used by processor elements,
- Determination of learning algorithm and parameters,
- Formation of training and test set.

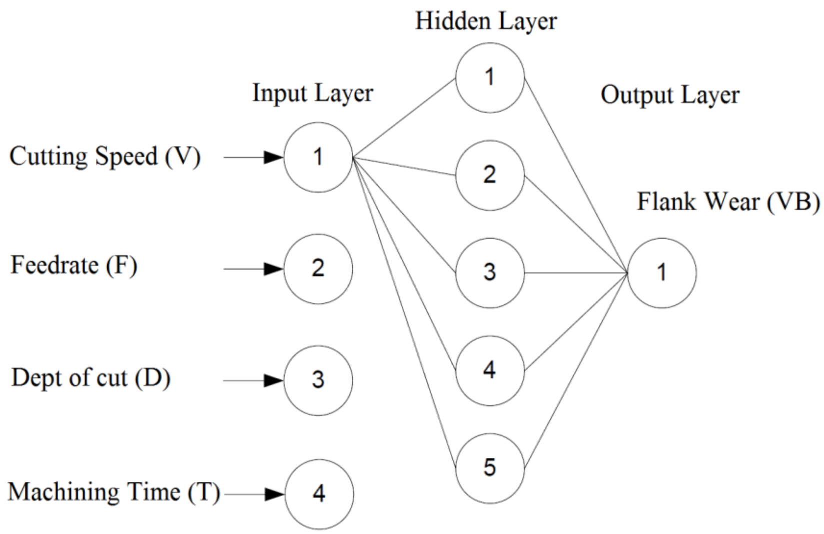

Figure 6. Structure of artificial neural network formed in the study

In case the above decisions are made wrong, system complexity shall grow. In order to make the best decision, the most rationalist approach would be to review similar studies in the literature and start designing and training the structure by parameters which had been determined for the problem to be applied. In addition, information such as how long the application will take and how much place it will occupy in memory, should be considered when designing the system.

With artificial neural network technique, while solution model for cutting tool wearing parameters are formed; cutting speed, feed, depth of cut and time variables which constitute the input layer were obtained from experimental studies. In the experimental studies made in conditions stated in the table, time dependent wearing of cutting tool was observed for certain cutting speed and feeds. For ANN structure developed in scope of this study, experimental cutting tool wearing data specified in the table were used. Amount of time dependent flank wear, which was obtained by the experiment results, was used in system training.

A calculation system was developed with MATLAB, which shall enable to obtain ANN input data from CNC code data. This developed system is integrated to the virtual machining system, and informs the user about critical wearing values. A number of manufacturing formulas were utilized in order to obtain input parameters by CNC code data.

To calculate machining time: $t = \frac{d.\pi.l.i}{v.1000.s}$

To calculate cutting speed; $v = \frac{\pi.d.N}{1000}$

To calculate depth of cut; $X_t = |X_2 - X_1|$ and $Z_t = |Z_2 - Z_1|$

Table 4. Prediction of tool wearing based on NC code

```
N25 G00 X0. Z5.;
N30 G01 Z0. F0.2;
N35 G01 X32.;
N40 G01 Z-18.;
N45 G01 X52.;
N50 G01 X80. Z-54.;
N70 G00 X110. Z110.;
N75 M30;
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Cutting speed: 156 m/dk
Feedrate: 0.2 mm/dev
Machining time: 3.4 s
Dept of cut: 2.5 mm

Predicted amount of wearing: 0,002 mm

Input layers determined in ANN are obtained by calculation of machining operations at rows of tool path (rows at G01, G02 and G03). According to above equations and input layer data obtained for machining lines, the amount of wearing for cutting tool is asked from ANN solution set. Amount of wearing determined for every row is added to the previous amount of wearing, and thus total amount of wearing is calculated. Since cutting tool will be drawn by the help of lines, its tip curve has been modeled by small line segments. Polygon based cutting tool is updated at every step as much as the total amount of wearing. In every step, decrement (wearing) in diameter of cutting tip end is simulated by the lines. [VB : (amount of wearing)] is entered under the code related with tool wearing data obtained in machining operations, and CNC code recorded in simulation system is updated. In virtual environment, the system informs user when pre-determined wearing values are exceeded, and thus it can be checked.

5. Results and Discussion

Today, since making both economic and quality production come into prominence, monitoring of tool status in machining sector has become one of the focused research areas. In tool status monitoring systems, two issues are generally observed which are tool chipping and tool wearing. Tool wearing is determined by microscopic examination of the worn area while wearing continues to develop, and this examination is maintained until wearing criteria reaches a certain value. In case cutting parameters are determined by experimental studies and types of workpiece and cutting tool material are very different, number of experimental studies to be conducted show increase. This case leads to cost increase and technical difficulties for experimental studies. It is not so possible to keep the ideal conditions of experimental studies in every study. Along with workpiece and cutting tool features, factors -also cutting parameters- such as cutting speed, feed rate, depth of cut, operation heat prepare the ideal conditions that determine the amount of tool wearing.

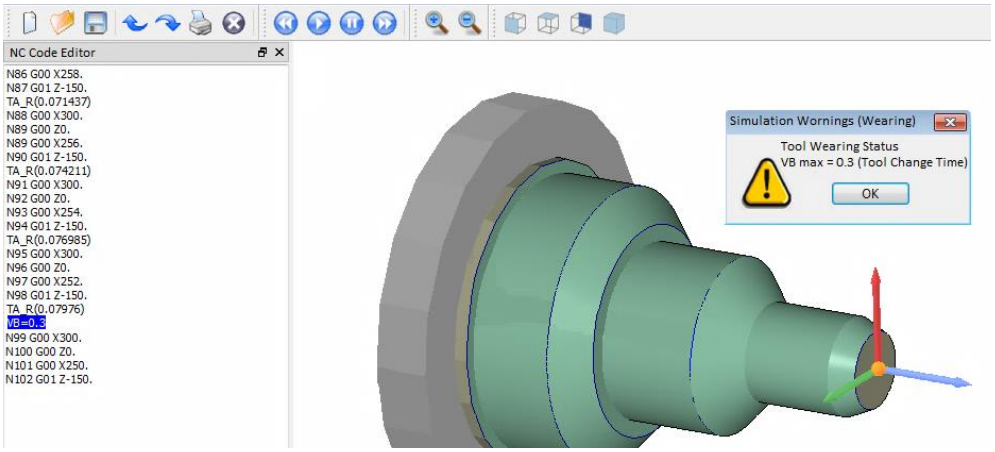

Figure 8. Identification of estimated tool wearing in virtual environment

In this study, apart from industrial CAM software, the effect of cutting tool wearing model obtained by artificial network technique to workpiece was reviewed in 3D virtual machining software environment. In virtual environment, polygon based modeling technique was utilized to define the interaction of workpiece and cutting tool while back propagation technique was utilized for the information of cutting tool wearing. Hardness of the material to be cut, type of the used cutting tool and amount of wearing took place on the cutting tool according to cutting parameters were reflected to 3D cutting tool model, and the amount of chip remained on the final workpiece was obtained.

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