Australian Journal of Basic and Applied Sciences, 3(1): 283-290, 2009
ISSN 1991-8178

Tool Condition Monitoring Using Cutting and Thrust Forces and Fuzzy Logic Technique

[1]Aidin Salimi and [2]Mohammad Zadshakouyan

[1]Mechanic Engineering Department, Faculty of Engineering, University of peyamnur, Tehran-Iran
[2]Manufacturing Engineering Group, Mechanical Engineering Department, University of Tabriz, Tabriz-Iran Tel: (+98) (411) (3393824) Fax: (+ 98) (411) (3356026)
E-mail: zadshakoyan@tabrizu.ac.ir or zadshakouyan@yahoo.com

Abstract: Real-time tool condition monitoring is one of the most important techniques to be developed in the automatic cutting processes. In this paper we proposed an intelligent system for tool wear monitoring. Experimental results of cutting and thrust forces are measured by a dynamometer and then the tool wear rates obtains for different values of forces from an analytica model. Using from experimental results of force and wear values of analytica model, fuzzy logic capabilities have been used to predict the wear rate as the force values increase. The simulation results presented with MATLAB software show the effectiveness of proposed system for on-line tool wear in drilling operation

Key words: tool wear monitoring,cutting and thrust force, fuzzy logic

INTRRODUCTION

Real-time tool condition monitoring is one of the most important techniques to be developed in the automatic cutting processes .In this processes it is simple to reduce overall time of machining by prevention of damage in machine tools. Although already many researches have been done for tool condition monitoring but there is no special methods that can be used practically in technology world without any restricts in motional capability of machine tools and without any economical feasibility (Zhang, M.Z., Y.B. Liu, 2001).

There are two methods for online tool wear estimation in cutting process.These methods have been classified into direct(optical.radioactive and electrical resistance,etc.) and indirect (AE, motor current,cutting force,vibration,etc.) sensing methods according to the sensors used. Recent attempts have concentrated on the development of the methods which monitor the cutting process indirectly (Xiaoli Li, 2001). Among direct methods the most commonly method that is used widely than others is optical method. There is a basic problem in this methods that tool can not be contact with workpiece (Li Xiaoli, Yao Yingxue, 1997; Xiaoli Li, Shiu Kit Tso, 200) therefore, to solve this problem indirect methods must be applied. In this methods tool wear monitoring is done by measuring parameters such as tool vibration, force cutting, acoustic emission, motor current, etc

Among indirect methods the method based on force measurment is one of the most widely methods that has been used to tool condition monitoring. Cutting forces (both thrust and torque) are very useful for drill wear monitoring. Because these forces generally increase as tool wear increases, thus, within the tool wear region cutting forces provide a good assessment of the tool conditions. If the cutting tool cannot withstand the increased cutting forces, catastrophic tool failure becomes inevitable. Consequently tool life which is a direct function of tool wear is best determinded by monitoring both torque and thrust force. In this method the accuracy of tool wear estimation is high than others. Because its measurment process will not be affected by structure of machine tools and the other noises. Therefore the measured dataes will be close to the real figures .The researches have posed thrust force and torque as a function of feed rate , drill diameter and flank wear have been investigated in reference (Xiaoli Li, 2001). Based on the experiments done with different material of workpiece, the formulas of torque and thrust force is posed as a function related to brinel hardning of workpiece, drill diameter, feed rate, flank wear and other parameteres (Erkki Jantunen, 2002). In on-line tool

Corresponding Author: Aidin Salimi, Mechanic Engineering Department, Faculty of Engineering, University of peyamnur, Tehran-Iran
Tel : (+ 98) (411)(5419742) Fax: (+ 98) (411) (5432926)
E-mail: salimy@pnu.ac.ir salimi952@yahoo.com

wear monitoring, there are two methods to obtain the thrust and cutting forces,while drilling process, 1: signals of anylatical models and 2: online measuring the forces by dynamometer. In this paper we have used from experimental dataes. Reportedly by researchers, first, we suggest a model that will showes the wear diagram, when the measured rate of cutting force are input in this model. Then ,the experimental dataes used in this paper, will be described. In the last, we propose an intelligent system with two inputs of cutting force and thrust force to represent the wear values allover the machining time using fuzzy logic technique. The simulation results presented with MATLAB software show the effectiveness of proposed system for on-line tool wear in drilling operation.The results obtained from simulation show that when the wear rate increases to a defined value, a signal sent to system and the simulation process will be stopped.

Tool Wear Model:

The most commonly used drill is the conventional conical point drill and in this paper, force models are developed for only this drill(Fig.1.). If the cutting tool cannot withstand the increased cutting forces, catastrophic tool failure becomes inevitable. Consequently tool life which is a direct function of tool wear is best determinded by monitoring both torque and thrust force. Generally thrust and torque magnitudes are 50% larger when machining the last hole than when machining the first hole. Moreover serious tool wear can cause 50% or 100% increase in the amplitude of force signals. Fig.2. illustrates the force signals for a new drill and a dull drill when drilling holes in a steel workpiece.

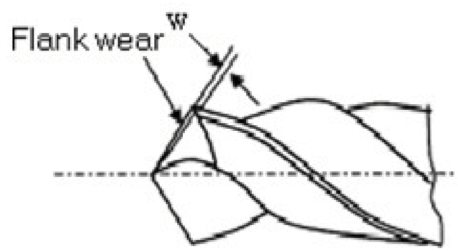

Fig. 1: shematic of a conical point drill (Kim, H.Y., J.H. Ahn, 2002)

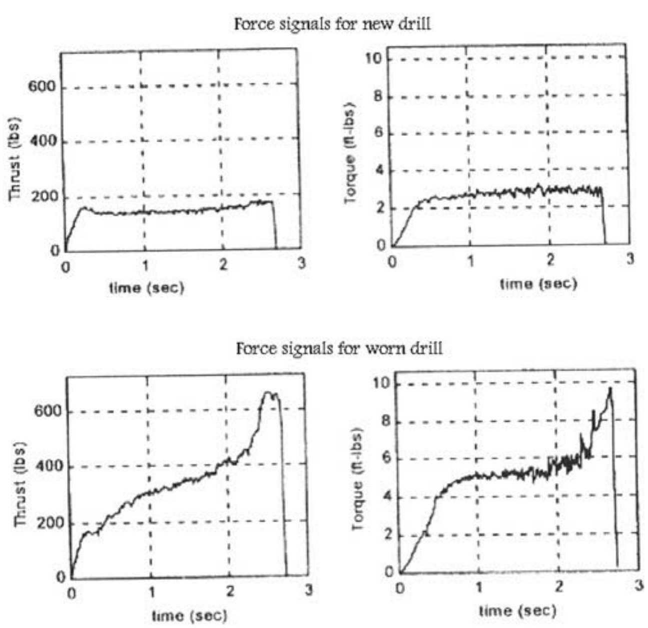

Fig. 2: torque and cutting force transition in relation to time.

Table 1: experimental results of thrust force and torque (Chandrasekharan, V., S.G. Kapoor, 1995)

Feed (mm/rev)	Speed (rpm)	diameter (mm)	point angle	Web Thichness (mm)	pilothole Diameter (mm)	Cutting lips		Total chisel		Entire drill	
						Thrust(N)	Torqe(Nm)	Thrust(N)	Torqe	Thrust(N)	Torqe(Nm)
0.229	400	15.9	118	2.3	3.2	1091.5	13.52	1037	1.29	2228	14.8
0.102	200	15.9	118	2.3	3.2	661.5	7.31	629	.548	1352	8.63
0.102	800	15.9	118	2.3	3.2	574.8	6.85	503	.505	1149	7.36
0.254	400	12.7	118	2.3	2.8	953.0	9.34	863	.919	1873	10.2
0.102	400	9.5	118	1.5	2.4	373.5	2.7	393	.356	811	3.06
0.102	400	12.7	118	2.3	2.8	490	4.9	510	.7	1000	5.7
0.102	400	15.9	135	2.3	4.4	539.8	4.42	299	.468	868	6.86
0.178	400	9.5	118	1.5	2.4	525.4	8.11	743	.601	1376	8.72

Because force signal measurments using a dynamometer may not be available in most machining applications a cost effective method for condition monitoring is necessary. In general, the process of tool wear impairs the sharpness of the tools cutting edge, increases the friction between the tool and workpiece, and also increases the power consumption.

As mentioned, When the machining operation is continued through the machining time tool begins to wear and the force necessary to operation increase. The force act on the lipe edge is consist of two element, one of its elements is created via machining operation(*Fcut*) and the other is created from friction between the tool and workpiece. Therefore the total force is (Kim, H.Y., J.H. Ahn, 2002).

$$F = F_{cut} + kwb \tag{1}$$

in the formula.1., *k* is a constant value , *w* is wear and b is cutting lengh. dynamical model of force for a new tool is investigated in references (Xiaoli Li, 2001).

State equations of the tool wear model have been considered in reference (Carrillo, F.J. and M. Zadshakoyan, 1998). In these equations, K1,K0*, K2, Cw*,*a,* Are the model parameters that are related to machining conditions. Estimating method of this parameters given in reference (Carrillo, F.J. and M. Zadshakoyan, 1998). In this model, X1 is diffusion wear, X2: initial wear,X3: linear wear, *Wf1*: composed of two initial and linear wear,*Wf2*:is diffusion wear that increases with temperature increasing . F0 is tool cutting force and Fc is the total force with giving attention to the wear effect and s is the laplace variable. Block diagram of wear model has been shown in figure .3. Fig.4 and Fig.5 show the effect of wear on cutting and thrust forces that have been simulated by wear model in MATLAB software. The state equations of wear model are:

$$\dot{X}1 = aK2Cw(X1 + X2 + X3) + K2F_0 \tag{2}$$

$$\dot{X}2 = \frac{1}{\tau}(K_0F_0 - X2) \tag{3}$$

$$\dot{X}3 = aK1Cw(X1 + X2 + X3) \tag{4}$$

$$Fc = F_0 + bCwW_f \tag{5}$$

Experimental Set up:

Drilling experiments were conducted on an OKUMA(MC-4VAE) CNC machining center Akistler (9273 A). Four-channel dynamometer was used to measure the thrust and torque forces. Matrial used is gray cast iron. Data has been sampled at 100Hz and stored in a pc. Tabl. 1 shows the parameters used in this paper (Chandrasekharan, V., S.G. Kapoor, 1995).

Fuzzy Inference System:

To design a fuzzy logic system in this paper we used MATLAB software with its capability at two methods of mamdani and sugeno. Because of its most commonly use, the base of simulation results in this paper is the mamdani method.

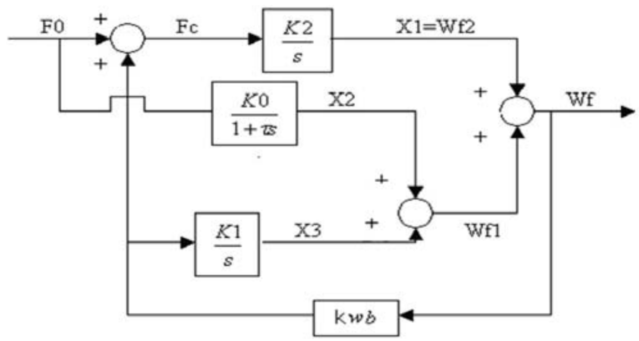

Fig. 3: block diagram of wear model.(Carrillo, F.J. and M. Zadshakoyan, 1998)

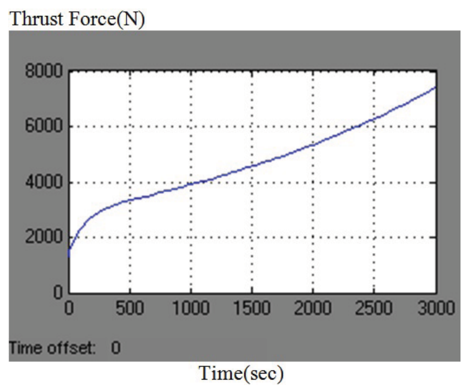

Fig. 4: thrust force diagram with effect of wear for drilldiameter 15.9mm,point angle118,helix angle 33,pilot hole diameter 3.2 mm, speed 200rpm, federate .102 mm/rev

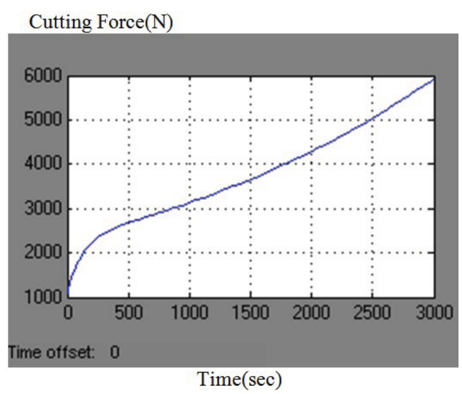

Fig. 5: cutting force diagram with effect of wear for drilldiameter 15.9mm,point angle118,helix angle 33,pilot hole diameter 3.2 mm, speed 200rpm, federate .102 mm/rev

There are many membership functions can be used. Based on their input and output transition behaviour, in this paper, we used triangular and trapezoid model for input and trapezoid for output.

Figures(6,7,8) respectively show the membership funcion of cutting force and thrust force as inputs and wear as output.

Number of rules applied for this system are 36. Their values are estimated by results of simulation. Number of rules is based on accuracy of work , data collection possibility and determining the type of membership function. The rules used in this system have been shown in fig.9.

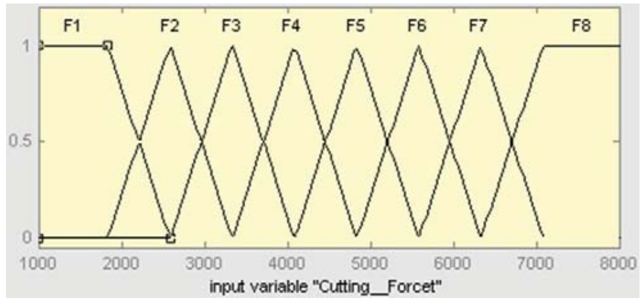

Fig. 6: cutting force membership function

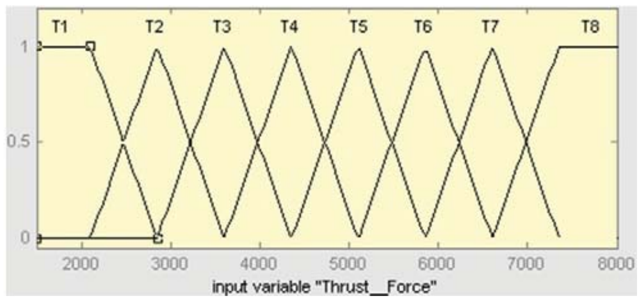

Fig. 7: thrust force membership function

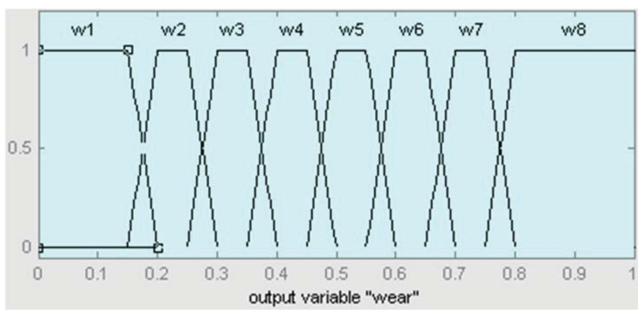

Fig. 8: wear membership function

The minimum value of wear in rule writing process, has been shown by, w_1 and the maximum value of wear that, the tool is worned out and breakage probablity is very high, been shown by w_8.

After writing the rules we can see the rules firing by selecting different inputs. We can see the values of fuzzy outputs and compare it with real values. Therefor by selecting value of rules we can be sure of system accuracy. This operation is done by selecting numerical values too or by moving pilot through the value of forces and understanding the wear proportion to force . Figure.10. shows the fuzzy rule base system.

In this paper we suppose that the value of wear for tool changing is .6mm but for a real tool it must be estimated and substituted in this system.The relationship between simulation results of fuzzy systems and the real results obtained from model will be shown while simulation progress.

In simulation process ongoing, when the value of wear reaches to .6mm, the process is stoped. Figure.11. shows the block diagram of fuzzy logic system.

Wear graph created from fuzzy output, is some different from real wear. But this difference is not very high. It means that using of fuzzy logic system for tool wear condition monitoring is realy effective method and can be applied in technology world too. Figure.12. shows the relationship between real wear graph and the wear graph obtained from fuzzy logic system. According to the graph it is found that accuracy of wear estimation by fuzzy logic system, while the value of wear reaches to a critical value, is very good.

1. If (Cutting__Forcet is F1) and (Thrust__Force is T1) then (wear is w1) (1)
2. If (Cutting__Forcet is F1) and (Thrust__Force is T2) then (wear is w1) (1)
3. If (Cutting__Forcet is F2) and (Thrust__Force is T1) then (wear is w1) (1)
4. If (Cutting__Forcet is F2) and (Thrust__Force is T2) then (wear is w2) (1)
5. If (Cutting__Forcet is F2) and (Thrust__Force is T1) then (wear is w2) (1)
6. If (Cutting__Forcet is F1) and (Thrust__Force is T2) then (wear is w2) (1)
7. If (Cutting__Forcet is F2) and (Thrust__Force is T3) then (wear is w2) (1)
8. If (Cutting__Forcet is F3) and (Thrust__Force is T2) then (wear is w2) (1)
9. If (Cutting__Forcet is F3) and (Thrust__Force is T3) then (wear is w3) (1)
10. If (Cutting__Forcet is F3) and (Thrust__Force is T2) then (wear is w3) (1)
11. If (Cutting__Forcet is F3) and (Thrust__Force is T4) then (wear is w3) (1)
12. If (Cutting__Forcet is F4) and (Thrust__Force is T3) then (wear is w3) (1)
13. If (Cutting__Forcet is F2) and (Thrust__Force is T3) then (wear is w3) (1)
14. If (Cutting__Forcet is F4) and (Thrust__Force is T4) then (wear is w4) (1)
15. If (Cutting__Forcet is F4) and (Thrust__Force is T5) then (wear is w4) (1)
16. If (Cutting__Forcet is F5) and (Thrust__Force is T4) then (wear is w4) (1)
17. If (Cutting__Forcet is F3) and (Thrust__Force is T4) then (wear is w4) (1)
18. If (Cutting__Forcet is F4) and (Thrust__Force is T3) then (wear is w4) (1)
19. If (Cutting__Forcet is F5) and (Thrust__Force is T5) then (wear is w5) (1)
20. If (Cutting__Forcet is F5) and (Thrust__Force is T4) then (wear is w5) (1)
21. If (Cutting__Forcet is F4) and (Thrust__Force is T5) then (wear is w5) (1)
22. If (Cutting__Forcet is F5) and (Thrust__Force is T6) then (wear is w5) (1)
23. If (Cutting__Forcet is F6) and (Thrust__Force is T5) then (wear is w5) (1)
24. If (Cutting__Forcet is F6) and (Thrust__Force is T6) then (wear is w6) (1)
25. If (Cutting__Forcet is F7) and (Thrust__Force is T6) then (wear is w6) (1)
26. If (Cutting__Forcet is F6) and (Thrust__Force is T7) then (wear is w6) (1)
27. If (Cutting__Forcet is F5) and (Thrust__Force is T6) then (wear is w6) (1)
28. If (Cutting__Forcet is F6) and (Thrust__Force is T5) then (wear is w6) (1)
29. If (Cutting__Forcet is F7) and (Thrust__Force is T7) then (wear is w7) (1)
30. If (Cutting__Forcet is F8) and (Thrust__Force is T7) then (wear is w7) (1)
31. If (Cutting__Forcet is F7) and (Thrust__Force is T8) then (wear is w7) (1)
32. If (Cutting__Forcet is F7) and (Thrust__Force is T6) then (wear is w7) (1)
33. If (Cutting__Forcet is F6) and (Thrust__Force is T7) then (wear is w7) (1)
34. If (Cutting__Forcet is F8) and (Thrust__Force is T8) then (wear is w8) (1)
35. If (Cutting__Forcet is F8) and (Thrust__Force is T7) then (wear is w8) (1)
36. If (Cutting__Forcet is F7) and (Thrust__Force is T8) then (wear is w8) (1)

Fig. 9: the rules of fuzzy system

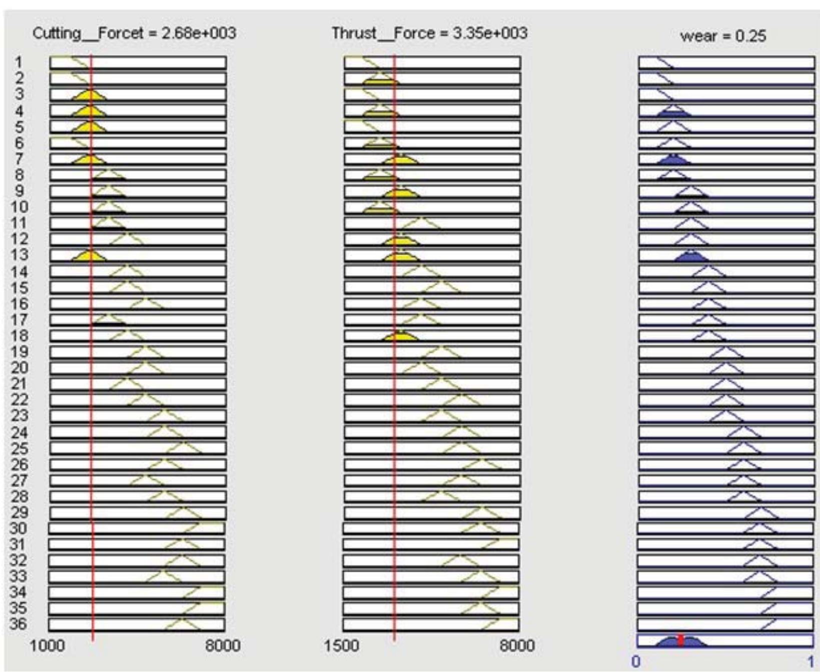

Fig. 10: fuzzy rule base system

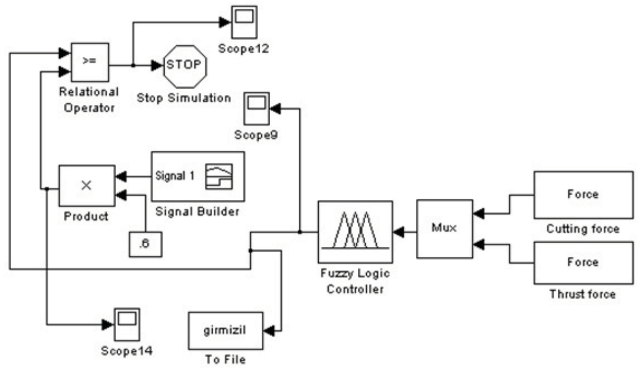

Fig. 11: simulated model of fuzzy logic system

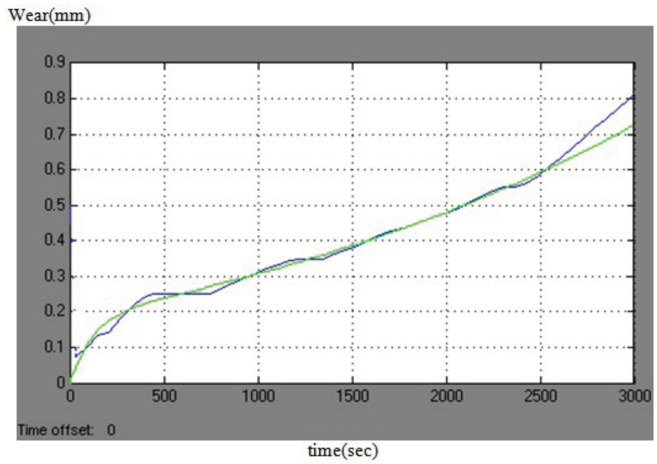

Fig. 12: comparing the fuzzy result (blue line) and the wear simulation result by the model (green line)

Conclusion:

In this paper we proposed an intelligent system to detect the tool wear rate in drilling process .Using the cutting and trust forces is one of its specifications. In this paper we used fuzzy logic to campare real wear with the wear rate obtained from the model and we found that fuzzy logic system has effective capabilities to predict the wear rate.

Summery Result of Research:

1- Tool wear estimation at lipe edge by measuring cutting force in drilling process is possible
2- By using of intelligent systems such as nueral network, fuzzy logic systems and control of system output parameters such as spindle and feed current, it is possible to use this model for on-line tool wear monitoring and it can be a step towards automation.

REFERENCES

Atsushi Matsubara, Yoshiaki Kakino, Yasumi Watanabe, 2000. Servo performence enhancment of high speed feed drives by damping control, 2000 japan.USA Flexible automation conference.

Carrillo, F.J. and M. Zadshakoyan, 1998. Adaptive observer for on-line tool wear estimation and monitoring in turning, using a hybrid identification approach, ECC, Bruxelles, Belgique, 1-4 juillet.

Chandrasekharan, V., S.G. Kapoor and R.E. Devor., 1995. A mechanistic approach to predicting the cutting forces in drilling:with application to fiber-reinforced composite materials, Journal of Engineering for Industry, Ebrahimi, M., R. Whalley, 2000. Analyses, modeling and simulation of stiffness in machine tool drives, Computer & Industrial Engineering, 38: 93-105.

Erkki Jantunen, 2002. A summary of methods applied to tool condition monitoring in drilling, International Journal of Machine Tools & Manufacture, 42: 997-1010.

Ertunc, H.M. and K.A. Loparo, 2001. Adecision fusion algoritm for tool wear condition monitoring in drilling, International Journal of Machine Tools and Manufacture, 41: 1347-1362.

Kim, H.Y., J.H. Ahn, S.h. Kim, S. Takata, 2002. Real-time drill wear estimation based on spindel motor power, Journal of material processing technology, 124: 267-273.
117: 559-570.

Li Xiaoli, Yao Yingxue, Yuan Zhejun, 1997. On-line tool condition monitoring system with wavelet fuzzy neural network,Journal of Intelligent Manufacturing, 8: 271-276.

Xiaoli Li, Shiu Kit Tso, Senior member, IEEE and jun wang, senior member, IEEE, 2000. Real - time tool condition monitoring using wavelet transform and fuzzy techniques, IEEE transaction system, man and cybernetics - part c: application and reviews, 30: 3.

Xiaoli Li, 2001. A brief review: acoustic emission method for tool wear monitoring during turning, International Journal of Machine Tools & Manufacture, 42: 157-165.

Xiaoli, S.K., Tso., 1999. Drill wear monitoring based on current signals, Elsevier Wear, 231: 172-178.

Zhang, M.Z., Y.B. Liu, H. Zhou, 2001. Wear mechanism maps of uncoated HSS tools drilling die-cast, Aluminum Alloy Tribology International, 34: 727-731.