Cutting Force Prediction for Armour Steel Drilling using Fuzzy Set Theory

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Abstract

Machining of Armour steel at high hardness is a highly interest of defence researchers, where most applications find in armour vehicles used such kind RHA. Usually tools are underutilized in the fully atomized CAD/CAM environment, this has the effect of increased frequency of the tool changes and therefore increased cost. Effective parameter prediction and there by increase the tool life is vital. This paper describes the prediction of cutting forces for given independent parameters such as cutting speed and feedrates on high hardness armour steel to and fuzzy based model developed to establish the cutting database for optimum utilisation of tool life without carrying out costly experiments. The model has been developed with cemented carbide cutting tool and fuzzy logic principles for predicting cutting forces of given cutting conditions in the hard drilling operation. The strategy and action of the skilled machine tool operator for selecting cutting speed and feedrate has been described by the fuzzy set theory. The results showed a good correlation between the experimental results with fuzzy logic model.

keywords : Rolled Homogeneous Armour(RHA), Fuzzy Logic, Hard Drilling

1. Introduction

Computer Numerically Controlled (CNC) machine tools have been widely used in industry for producing high precision machined parts. Automatic machining operation of CNC machine tools requires appropriate cutting parameters prescribed by the programmers, based upon their experience and knowledge. Usually, conservative parameters are employed to avoid tool breakage and system instability problems [5] that will result in the increase of machining time and reduce productivity of CNC machines. Hard machining is performed under unique technological and thermo mechanical conditions and as expected, the process mechanisms (chip formation, heat generation, tool wear) differ substantially from those observed in machining soft materials [4].

Nowadays machining data selection is an important component of the CAD/CAM system and plays a very important role in the efficient utilization of machine tools and influences the product quality. For this reason rule based fuzzy system have been incorporated into many CAD/CAM system in order to get optimum machining parameters[1].

The premise of these model-based control strategies implemented on complex dynamic systems is to establish a reasonable mathematical model for controller design. This paper deals with the application of fuzzy in order to use the experimental data for carbide tool optimization of drilling parameters so as to achieve targets of enhancing tool life and improving workpiece surface finish [7]. The fuzzy logic prediction modules were operating upon different set of rules [8]. The min-max based rule applied here for estimating the Thrust force (Ft) and Torque (Tq) of hard drilling process [9].

2. Artificial Intelligent Control System

The evolution in the control area has been fuelled by two major concerns, the need to deal with increasingly complex systems, and the need to accomplish increasingly demanding design requirements with less prior knowledge of the system and its environment, that is, the need to control under increased uncertainty. The use of the artificial intelligent control techniques in control system can be seen as a natural step in the development of control methodology to meet the complex challenges, such as machining process control.

2.1 Data fuzzification

Fuzzy logic is a discipline that has been successful in automated reasoning of expert systems. Uncertainty, vagueness, ambiguity, and impreciseness are some of problems found in relationships between inputs and outputs of real world systems, and these can be tackled effectively by utilizing treatment of fuzzy logic. Fuzzification is a kind of process in which the input data, precise or imprecise, is converted into a kind of linguistic form, which is easily perceptible by the human minds, for example very short and highly hard etc. Expert system then uses these fuzzified data to give answers to imprecise and vague questions and also describe the reality level of those answers.

2.2 Fuzzy output defuzzification

Defuzzification process is defined as the conversion of a fuzzy quantity, represented by a membership function, to precise or crisp quantity. There are two commonly used techniques for defuzzification of fuzzy quantities [1]. They are max method and union centroid method. In cases where the membership function, characterizing the fuzzy quantity, has a unique peak point the crisp value corresponding to the peak of the function is taken to be the best representative value of the fuzzy quantity. This is called max method. For the second method of defuzzification, the weighted average of the membership functions or the centre of the gravity of the area bounded by the membership function curve is computed to be most typical crisp value of the fuzzy quantity. All the output fuzzy sets after rules application will undergo union operation and its centroid will be calculated in the union centroid method. Weighted centroid methods suggested in this paper. The method is similar to union centroid except undergoing fuzzy union operation.

2.3 Fuzzy models

The main objective of fuzzy logic based system identification is to model the system behavior, i.e., to explain the interactions among inputs and the relationships between the inputs and the output of a system, in the form of a fuzzy rule based system. A two-input-two-output fuzzy control system for drilling operations is used in this study. The fuzzy logic controller (FLC) consists of a membership function, a knowledge base, an inference engine, and a defuzzifier. The function of each block is described as follows.

3.1 Fuzzy input membership function

Cutting speed is the most concerned parameter of the machining, It is combined with the other attributes as linguistic data for the cutting force process. There are six membership functions used for cutting speed that show the degree of potential as Very Slow speed, Slow speed, Medium speed, Upper medium speed, High speed and Very High speed denoted as VSL,SLO,MED,UME,HIS and VHS respectively. Similarly the another input feed rate had the six membership Viz., Very Slow feed, Slow feed, Medium feed, Upper medium feed, High feed and Very high feed denoted as VSF,SLF,MEF,UMF,HIF and VHF respectively. The input membership function is well-distributed as triangle shapes which are shown in Figure 1 and Figure 2.

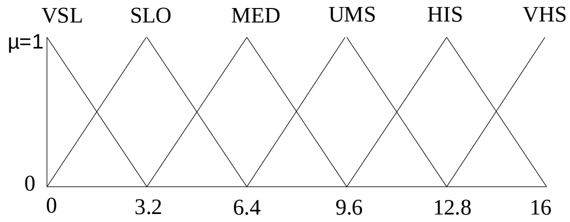

Figure 1 Membership function of cutting speed (V)

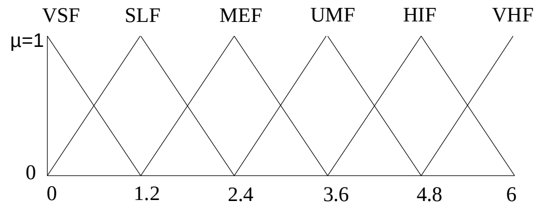

Figure 2 Membership function of feedrate (f)

3.2 Fuzzy output membership function

In this process, input can be combination of two features cutting speed and feedrate. The membership function for output fuzzy variables (thrust force and torque) are shown in Figs 3 & 4 respectively.

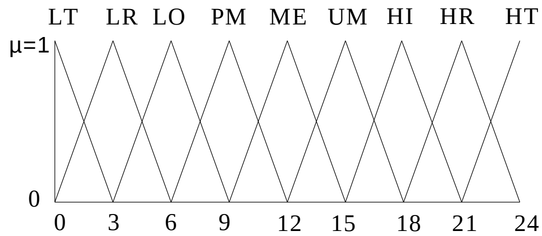

Figure 3 Membership function of thrust force (Ft)

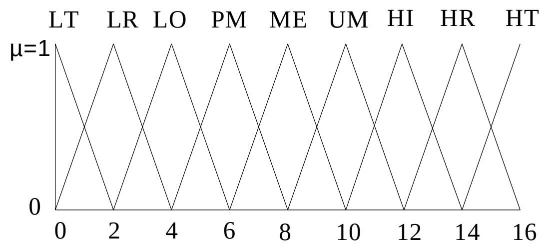

Figure 4 Membership function of torque (Tq)

There are nine membership functions for thrust force and torque that shows the degree of potential as Lowest, Lower, Low, Pre medium, Medium, Upper medium, High, Higher and Highest denoted as LT,LR,LO,PM,ME,UM,HI,HR and HT respectively.

3.3 Fuzzy set rules

The model applies the straightforward fuzzy rules, which are, If the cutting speed is Very slow THEN the thrust force is Lowest. A set of fuzzy rules has been constructed for the drilling operation, based on the knowledge extracted from the skilled machine tool operator, Tool manufacturer's catalog or machining data handbook [2] they are as follows:

Table 1 Fuzzy rules in matrix form

Cutting speed (V)	Feed rate (f)					
	VSF	SLF	MEF	UMF	HIF	VHF
VSL	LT LR	LR LR	LR LO	LO LO	LO PM	PM PM
SLO	LR LR	LR LO	LO LO	PM PM	PM ME	ME ME
MED	LT LR	LR LR	LR LO	LO PM	LO PM	PM ME
UMS	LR LO	LO PM	PM PM	ME ME	UM UM	HR HI
HIS	PM PM	ME PM	ME UM	UM ME	UM ME	HI UM
VHS	ME PM	ME ME	UM ME	HI UM	HR HI	HT HT

3.3.1 Fuzzy rules in Linguistic Form

1. If cutting speed is VSL (very slow speed) AND Feedrate is VSF (very slow feed) THEN Thrust force will be LT (Lowest) AND Torque will be LR (Lower)

2. If cutting speed is VSL (very slow speed) AND Feedrate is SLF (slow feed) THEN Thrust force will be LR (Lower) AND Torque will be LR (Lower)
   ……..

36. If cutting speed is VHS (very high speed) AND Feedrate is VHF (very high feed) THEN Thrust force will be HT (Highest) AND Torque will be HT (Highest)

The above rule has an AND operation and using min-max algorithm this rule will yield a result, that is minimum between the degree of cutting speed AND feedrate and can be defined as follows

$$\mu(LT, LR) = \min\{\mu(VSL), \mu(VSF)\}$$

Taking all the combinations of the two inputs and applying the AND operation and it yields the following four membership values, for example the [1 1] the input combinations are shown in Figure 5 and Figure 6.

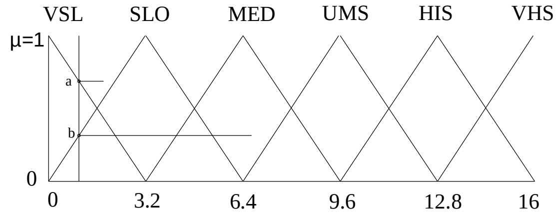

Figure 5 Fuzzy rule interaction with cutting speed

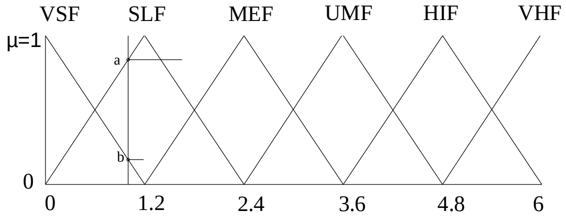

Figure 6 Fuzzy rule interaction with feedrate

1. VSL (0.6875) AND VSF (0.1667) will yield LT (0.1667) AND LR (0.1667) - Rule 1.

2. VSL (0.6875) AND SLF (0.8333) will yield LR (0.6875) AND LR (0.6875) - Rule 2.

3. SLO (0.3125) AND VSF (0.1667) will yield LR (0.1667) AND LO (0.1667) - Rule 7.

4. SLO (0.3125) AND SLF (0.8333) will yield LR (0.3215) AND LR (0.3215) - Rule 8.

Table 2 Thrust Force value

	Thrust force							
	0	1	2	3	4	5	-	24
LT	0.17	0.17	0.17	0	0	0	0	0
LR	0	0.33	0.67	0.69	0.67	0.33	0	0
LR	0	0.17	0.17	0.17	0.17	0.17	0	0
LR	0	0.31	0.31	0.31	0.31	0.31	0	0

Table 3 The 'max' value for thrust force

0	1	2	3	4	5	-	24
0.17	0.33	0.67	0.69	0.67	0.33	0	0

$$Average\ thrust\ value \Rightarrow \sum\left(\frac{Avearg\,e\ value \times \mu(A)}{\mu(A)}\right)$$

EQ. (1)

The centriod Equation (1) used to calculate the thrust force index (TFI) as follows, and the defuzzied thrust force shown in Figure 7

$$\Rightarrow TFI = \frac{(0*0.17)+(1*0.33)+(2*0.67)+(3*0.69)+(4*0.69)+(5*0.33)}{(0.17+0.33+0.67+0.69+0.67+0.33)}$$

TFI = 2.82

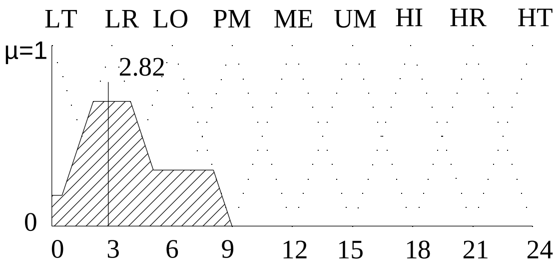

Figure 7 Truncated defuzzified thrust force

THRUST FORCE CRISP VALUE =

$$\left\{\left(\frac{TFI}{24}\times Ft_{diff}\right)+Ft_{\min}\right\} \qquad \text{Eq.(2)}$$

$$\Rightarrow\left\{\left(\frac{2.82}{24}\times 1800\right)+700\right\}$$

= 911.5 N

The outcome of Equation 2 gives the interpretation of crisp value for the given cutting condition, say for the value of V = 22.5 m/min and f =0.066 mm/rev (75mm/min) for the Ø6.4mm twist drill the thrust force is Ft = 912 N. Similarly the torque index generated using min-max rule as shown in Table 4 and 5 respectively.

Table 4 Torque value

	Torque force								
	0	1	2	3	4	5	6	-	16
LR	0	0.17	0.17	0.17	0	0	0	0	0
LR	0	0.5	0.69	0.5	0	0	0	0	0
LO	0	0	0	0.17	0.17	0.17	0	0	0
LR	0	0.32	0.32	0.32	0	0	0	0	0

Table 5 The 'Max' value for torque

0	1	2	3	4	5	6	-	16
0	0.5	0.69	0.5	0.17	0.17	0	0	0

$$Average\ torque\ value \Rightarrow \sum\left(\frac{Avearge\ value\times\mu(A)}{\mu(A)}\right)$$

Eq. (1)

The centriod Equation (1) used to calculate the torque index (TQI) as follows, and the defuzzied torque shown in Figure 8.

$$\Rightarrow TQI = \frac{(1*0.5)+(2*0.69)+(3*0.5)+(4*0.17)+(5*0.17)}{(0.5+0.69+0.5+0.17+0.17)}$$

TQI = 2.42

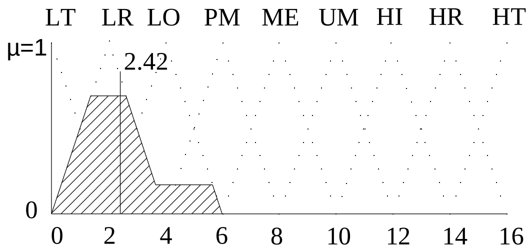

Figure 8 Truncated defuzzified torque

TORQUE CRISP VALUE =

$$\left\{\left(\frac{TQI}{16}\times Fq_{diff}\right)+Fq_{\min}\right\} \qquad \text{Eq.(2)}$$

$$\Rightarrow\left\{\left(\frac{2.42}{16}\times 1.95\right)+0.8\right\}$$

=1.09 N-m

The outcome of Equation 2 gives the interpretation of crisp value for the given cutting condition, say the value of V = 22.5 m/min and f =0.066 mm/rev (75mm/min) for the Ø6.4mm twist drill the torque is Tq = 1.09 N-m.

4. Results and Discussions

4.1 Cutting force

The drilling thrust force depends on the geometry of the drill (diameter, point angle, lip length, evolution of the cutting angles along the edges, etc.) as well as on the cutting conditions (cutting speed, feed rate, lubrication, etc.) and on the material's properties. The cutting force has been measured by using dynamometer (Kistler 9271A). Though different types of dynamometers are available for different cutting applications, the compliance of machine tools, leading to chatter and dimensional error, and lack of overload protection limit their application owing to high cost. The control of the cutting force of a drill is of particular interest when a high surface finish and part dimensional accuracy are desired.

4.2 Work material properties

The material used is the ARMOX 500T steel. The material finds wide application for vehicle armor and respective mechanical properties of material has been denoted in Table 6 as follows.

Table 6 Mechanical properties of material

Hardness (HRc)	Charpy-V40 10x10 (J)	Yield strength (MPa)	Tensile strength (MPa)	% Elongation
50-52	min 25	min 1275	1480-1750	11-13

4.3 Tool geometry specification

The solid carbide with parallel shank twist drill was used in this experiment. The geometric parameters of conventional two flute twist drills are determined by their manufacturing parameters. The key features of the drill are the diameter, the lip relief angle, the point angle, web thickness and the helix angle are shown in Table 7.

Table 7 Drill nomenclature

Drill Dia (D)	Lip relief Angle	Point Angle (β)	Web Thickness (w)	Helix Angle (h)
6.4mm	12°	118°	1.2mm	30°

Table 8 Comparison of Experimental and Fuzzy crisp cutting force values

Cutting condition		Index value		Experimental		Fuzzy based value	
CS	FR	TFI	TQI	Thrust Force	Torque	Thrust Force	Torque
20	0.06	0.92	2	770	0.992	826.9	1.04
	0.08	4.51	4	850	1.248	1048.1	1.29
	0.1	9.01	6	1075	1.632	1325.6	1.53
30	0.06	2.58	2	785	1.056	929.10	1.04
	0.08	7.5	6	950	1.440	1232.5	1.53
	0.1	13.5	10	1950	2.176	1602.5	2.02
40	0.06	12	6	1750	1.216	1510.0	1.78
	0.08	16.5	9	1900	1.792	2089.6	2.38
	0.1	23.1	15.4	2125	2.624	2194.5	2.68

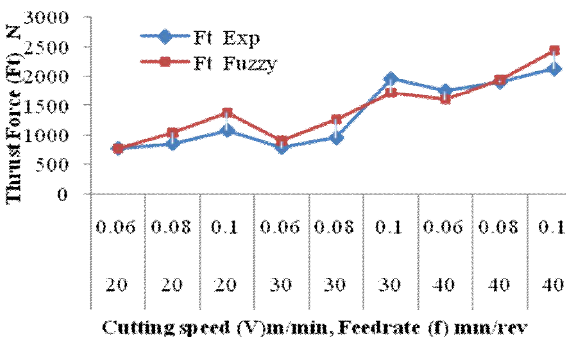

Figure 9 Comparison of experimental and fuzzy crisp values of thrust force (Ft)

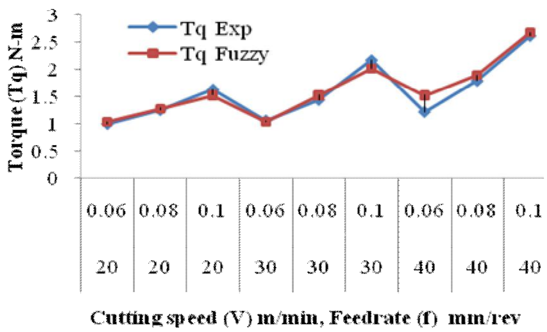

Figure 10 Comparison of experimental and fuzzy crisp values of torque (Tq)

5. Conclusions

The conclusions resulting summery as follows

- ✓ The fuzzy model gives good prediction to the experimental results.
- ✓ The relationship of given cutting condition to the cutting forces were evaluated using fuzzy set theory.
- ✓ The fuzzy model can be used to adapt CIM(Computer Integrated Manufacturing) for upcoming technologies.
- ✓ This paper describes the development stages of a fuzzy logic model for metal cutting. The model is based on the assumption that the relationship between the cutting condition of a given material and the cutting forces is an imprecise relationship, and can be described and evaluated by the theory of fuzzy sets.
- ✓ The objective of the model is to facilitate the computerization process of the vast machining information.

6. References

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