International Journal of Scientific & Engineering Research, Volume 5, Issue 12, December-2014
ISSN 2229-5518

FUZZY LOGIC BASED DRILLING CONTROL PROCESS

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***Abstract*:-Fuzzy logic is defined as a perfect mathematical theory of inaccurate reasoning processes for human in linguistic terms it will allows us model for reasoning process. The reduction in crude material and labour attrition due to the continuing search the control of industrial manufacturing process is of great economic import from last two decades, the use of intelligent manufacturing system, which is the next step in the monitoring manufacturing process, has been researched through the application of artificial neural networks. In this paper, the fuzzy logic model has been used in the drilling operation to select drilling speed for two different materials. The bearing concern between a given material hardness and drilling speed can be described and evaluated by the fuzzy relation for different cutting tool materials and different whole diameters and feed rates. The application of the developed fuzzy models an example is given to express and verify. The results obtained by from machining data handbooks are compared with the corresponding ones to shown decent fit.**

***Keywords*: Fuzzy logic, drilling speed, work-piece material hardness**

I. INTRODUCTION

Fuzzy logic deals with uncertainty in engineering by attaching degrees of certainty to the answer to a logical question. Commercially, fuzzy logic has been used with great success to control machines and consumer products. Selection of machinability data are includes choosing the appropriate machining parameters like speed, feed rate, and depth of cut play an important role in the efficient utilization of machine tools and thus significantly influences the overall manufacturing cost.

Very little literature is available in application of fuzzy logic in drilling operation. Hashmi, K. et al [1] have developed a fuzzy logic model used to select cutting speeds for three different materials in drilling operation. The relationship between a given material hardness and drilling speed was described and evaluated by fuzzy relation for different cutting tool materials and different hole diameters and feed rates. Saleh M. AMAITIK [2] fuzzy logic models to select machining parameters (cutting speed and feed rate) in automated process planning (CAPP) systems. Each model utilizes two-input and two-output variables which are partitioned into several fuzzy sets according to their minimum and maximum values allowed to control the model. Zahari Taha et al [3] introduce a fuzzy logic-based user-friendly system has been developed for selecting machining parameters in turning operation. S.V. Wong et al [4] have suggested a new fuzzy model for machinability data selection, which is different from El Baradie. The model suggested by El Baradie was a one-input–one-output fuzzy relationship by considering the depth of cut as a discrete parameter. Emel Kuram et al [5] apart from the literature a model depended on fuzzy logic approach on prediction of drilling parameters with vegetable based cutting fluids was established and the result obtained from fuzzy logic were compared with the results based on regression and experiment.

In this work, a fuzzy logic model has been developed for selecting drilling speeds in the drilling operation. Data for two different materials have been used for different grades of cutting tools and various Hardness range. The objective of this work is to facilitate the operator to select drilling speed for various hardness of material of different grades from expert database Fuzzy logic is not the answer to all technical problems, but for control problem where simplicity and speed of implementation is important then fuzzy logic is a strong candidate.

II. MEMBERSHIP FUNCTION

In fuzzy logic the measured signal x in control system which is a error signal convert into a set of variables is the first step in fuzzy logic. This is called fuzzy classification or fuzzification [6]. It is done by giving values (these will be our fuzzy variables) to each of a set of membership functions. The values for each membership function are labeled $\mu(x)$, and are determined by the original measured signal x and the shapes of the membership functions. The value of membership function ranges between 0 and 1. And it shows how much a variable matches a fuzzy set. A common fuzzy classifier splits the signal x into five fuzzy levels as follows [6]

LP: x is large positive
MP: x is medium positive
S: x is small
MN: x is medium negative
LN: x is large negative

Fuzzification divides the input and output variables into fuzzy sets. The system is based on the relationship that exists for any specific material between its hardness (input) and the corresponding drilling speed (output). The first step of fuzzification process is to define the fuzzy sets in the input and output variables. The possible domain interval of both the inputs and outputs are divided into a number of regions in such a way that they overlap each other. The length of region may differ for each variable and one membership function is assigned to each region. The fuzzy sets for input fuzzy variable (HARDNESS) and output fuzzy variable (DRILLSPEED) are shown in Fig. 2.

Membership functions for three of these five fuzzy levels are shown in Figures 1. So, for example, the value (or fuzzy variable) for the MP membership function and a signal value of x = 2.5v is

$$\mu\ MP\ (2.5) = 0.5.$$

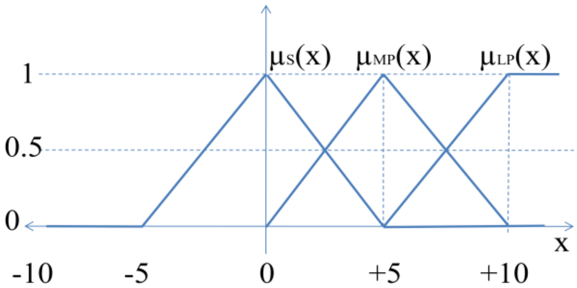


Figure1. Membership Functions for Zero Membership (S: x is small), Medium Position Membership (MP), Large Position Membership (LP).

Table 1
Recommended drilling speeds for three different materials using high-speed steel tools

Tool materials grades (HSS) AISI No.	Hardness range (BHN)	Mid point Hardness (BHN)	Work materials	
			Carbon steel, (medium carbon)	Mild steel, (low carbon)
			Drilling speed (m/min)	Drilling speed (m/min)
M1, M7	125-175	150	21	20.5
M1, M7	175-225	200	19	21
M1, M7	225-275	250	18	18
M1, M7	275-325	300	15	15
M1, M7	325-375	350	14	12

III. FUZZY RULES FOR DRILLING OPERATION

A fuzzy model uses a linguistic statements IF-THEN it is a fuzzy rules involving different fuzzy sets for input and output variables. Fuzzy rules play key role in representing fuzzy sets for input fuzzy variable hardness and output fuzzy variable drill speed is shown in figure.

If the material Hardness is Soft Then Cutting speed is high. Fuzzy rule describing the selection of cutting speed in drilling operation is given as:

Rule 1. If material hardness is VS (very soft), then speed is VHI (very high).

Rule 2. If material hardness is SO (soft), then speed is HIG (higher).

Rule 3. If material hardness is ME (medium), then speed is MDH (medium high).

Rule 4. If material hardness is MH (medium hard), then speed is MSL (medium slow).

Rule 5. If material hardness is HA (hard), then speed is SLO (slow).

Rule 6. If material hardness is VH (very hard), then speed is VSL (very slow).

Where material hardness is input variables and cutting speed is output variable. "Soft", "Medium", and "High" are fuzzy sets. A set of fuzzy rules have been constructed for each fuzzy model, based on the knowledge extracted from machining data handbooks.

In the fuzzy logic, firstly identified the ranges of parameters input and output used in the study then to obtain fuzzy sets

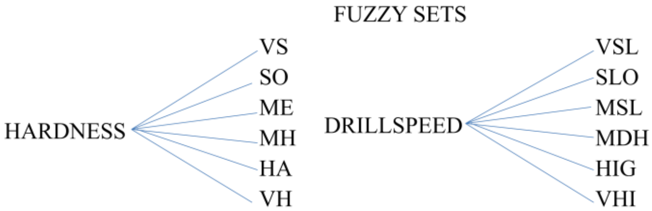


Fig. 2. Input and output fuzzy variables.

Table 2
Fuzzy expressions for input and output fuzzy sets

Abbreviation	Expression for Input	Expression for Output
VS	Very soft	Very slow speed
SO	Soft	Slow speed
ME	Medium	Medium slow speed
MH	Medium hard	Medium high speed
HA	Hard	High speed
VH	Very hard	Very high speed

IV. MEMBERSHIP FUNCTIONS

A fuzzy set are described by a triangular shape in that a 50% overlapped is adjust by other ones. Membership functions for each fuzzy set for input fuzzy variable HARDNESS and for output fuzzy variable DRILLSPEED are shown in Fig. 3.

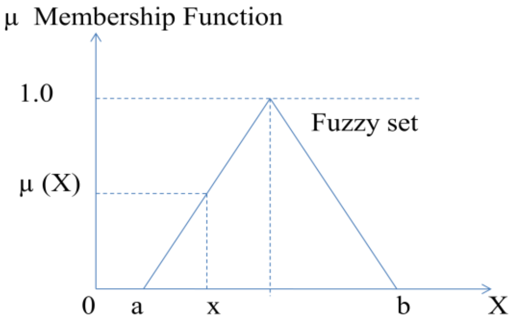


Figure 3. A triangular membership function of a fuzzy set

The membership of a number x from the real line is often denoted by μ(x). The membership functions characterize the fuzziness in a fuzzy set whether the elements in the set are discrete or continuous in graphical from for eventual use in the mathematical formation of fuzzy set theory [3]. To allow controlling the system we can divided the input universe ‘material hardness’ into the minimum and maximum value on the basis of hardness has been break in the range of 0-20, above the range of this any values assumed to be infinity. In that value ‘0’ represent material hardness is almost minimum is called ‘hardness min’ and the value ‘20’ will present material hardness is maximum is called ‘hardness max’.

In the similar manner the output variable drilling speed has been divided according to range of speed required from 0-10. In that the ‘0’ value represents the minimum speed and ‘10’ value represents the maximum speed for any value of output speed range. There is no standard method of choosing the proper shape of the fuzzy sets of the control variables. Trial and error methods are usually exercised [2]. In this system an equal sided triangular shape membership function is chose for the input-output (HARDNESS and DRILLSPEED) fuzzy variables as shown in figures 4.

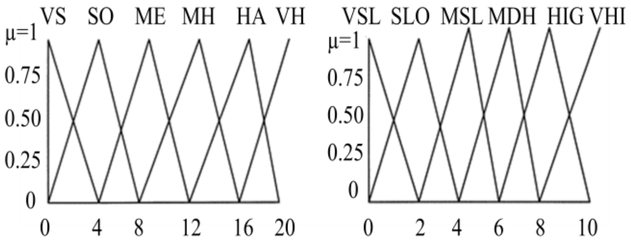


Fig. 4. Membership function.

V. DEFUZZIFICATION

The last step in building a fuzzy logic system is turning the fuzzy variables generated by the fuzzy logic rules into a real signal again. The fuzzy logic process which does this is called defuzzification because it combines the fuzzy variables to give a corresponding real (crisp or non-fuzzy) signal which can then be used to perform some action. Defuzzification is a mathematical process used to convert a fuzzy set or fuzzy sets to a real number. It is necessary step because fuzzy sets generated by fuzzy inference in fuzzy rules must be somehow mathematically combined to come up with one single number as the output of a fuzzy model.

Defuzzification is a much more complex process than fuzzification there are several choices to be made, and many different methods have been proposed. We will not attempt to explore the entire array of possibilities; instead, we will lay out the areas where choices must be made, and indicate which choices are most commonly used. Every fuzzy model uses a defuzzifier, which is simply a mathematical formula, to achieve defuzzification. For fuzzy models with more than one output variable, defuzzification is carried out for each of them separately but in a very similar fashion. In most cases, only one defuzzifier is employed for all output variables, although it is theoretically possible to use different defuzzifiers for different output variables.

VI. FUZZY RELATION

In this work, five fuzzy models have been developed for selection of machining parameters. Each model utilizes one input variables and one output variables. A fuzzy relation is the relationship between the input (HARDNESS) and the output (SPEED) of the control system. The relationship between the input and the output can be found using Cartesian product expressions of the two sets [2].

R=input * output

Where the asterisk represents the Cartesian product.

In the case of Rule 1, the relationship would be

R1= (material hardness) VS * (speed value) VHI

This has a membership function of

μR1= min {μ very soft material; μ very high speed}

Assume that triangular fuzzy numbers start rising from zero at x=a; reach a maximum of 1 at x=b; and decline to zero at x=c. Then the membership function μ(x) of a triangular fuzzy number is given by [10]

$$\mu(x) = 0;\ x \le a$$
$$= (x - a)/(b - a);\ a < x \le b$$
$$= (c - x)/(c - b);\ b < x \le c$$
$$= 0;\ x > c$$

To derive simple formulas for the quadratic fuzzy numbers, it is best to consider an effective translation of the x axis to the points x=a for the first region, x=b for the second and third regions, and x=c for the fourth region. At these three points the first derivatives are 0, and the membership functions are given by [10]

For $a \le x \le a+b/2$; $\mu(x) = k1(x - a)^2$

For $a+b/2 \le x \le b$; $\mu(x) = 1 - k1\,(b - x)^2$

For $b \le x \le b+c/2$; $\mu(x) = 1 - k2\,(x - b)^2$

For $b+c/2 \le x \le b$; $\mu(x) = k2\,(c - x)^2$

The constants k1 and k2 are easily evaluated by realizing that at x = (a+b)/2 and x = (b+c)/2, the memberships are 0.5.

VII. RULE COMBINATION

The First and second relations can be combined together by using an `or' function to produce one which allows an input (HARDNESS) to be either VS (very soft) or SO (soft). The `or' function is represented as the maximum of the membership values of the two different relations. The fuzzy statement combined from the two fuzzy rules R1 and R2 is as follows:

if material HARDNESS is VS;
then DRILLSPEED is VHI
or
if material HARDNESS is SO;
then DRILLSPEED is VHI

which is equivalent to:

$$\mu R_1 + \mu R_2 = \max \{\mu R_1; \mu R_2\}$$

Thus, the total combination of the six relations using `or' operator is the maximum of membership values and can be represented in the relation μR, which has a membership function of

$$\mu R = \max \{\mu R1; \mu R2; \mu R3; \mu R4; \mu R5; \mu R6\}$$

This relation is in fact the model of the action of the process planning engineer/machine tool operator. Combining this relation with any value of the material hardness that lies in its universe (0±20) results in the required average cutting output for the operation. The defuzzified output which gives the average speed value can be obtained from the following formula:

$$\text{Average value} = \frac{\sum \text{speed value} \times \mu(s)}{\sum \mu(s)}$$

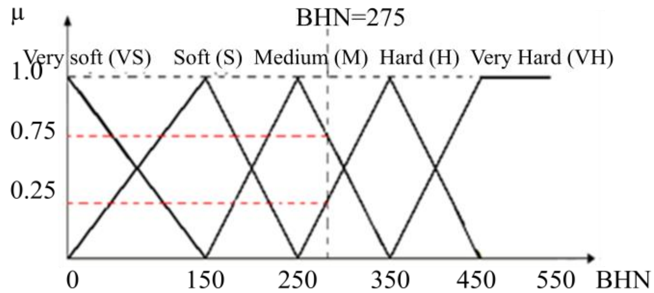
Table 4 gives the relation between the hardness universe (0±6) and the average values of output speed.

Table 4
Average speed values

Hardness universe partitioning	Average speed value
0	9.67
1	9.00
2	8.50
3	8.25
4	8.00
5	7.44
6	7.00

VIII. MACHINING PARAMETERS SELECTION EXAMPLE

To demonstrate the application of the proposed fuzzy models, an example is being presented to select cutting speed for twist drilling of carbon steel work piece with high speed steel tool. Consider the situation where work material hardness, *BHN*, is equal to 275 and hole diameter, *D*, is equal to 15 mm. Using the fuzzification formula of triangular membership function, the crisp material hardness value of 275 belongs to fuzzy set Medium to a degree of 0.75 and to fuzzy set Hard to degree of 0.25. Similarly, crisp hole diameter value of 15 belongs to fuzzy set Medium to degree of 0.85 and to fuzzy set Large to degree of 0.15, see Figure 5.



Material hardness membership function
Figure 5. Fuzzification of the input values

These fuzzified values are then passed to the fuzzy rules knowledge base through the inference method used. The only rules that will have degree of fulfillment, DOF (it is a measure of the degree of similarity between the input and the premise of the rule) greater than zero will fire up. In the case of this example the following four rules will fire up (see Table 2).

R1 **IF** bhn is **M** and d is **M THEN** v is **L**, f is **M**
R2 **IF** bhn is **M** and d is **L THEN** v is **L**, f is **M**
R3 **IF** bhn is **H** and d is **M THEN** v is **VL**, f is **S**
R4 **IF** bhn is **H** and d is **L THEN** v is **VL**, f is **M**

Using the Max-Min inference method of DOF (i.e. the min (^) interpretation of AND), each rule contributes the machining parameters values. The degree of fulfillment of each rule can be calculated as follows (see Figure 6 for evaluation steps);

R1: DOF1 = μ medium (275) ^ μ medium (15) = 0.75 ^ 0.85 = 0.75.
Contributes Low to cutting speed and Medium to feed rate.
Similarly, rules R2, R3, and R4 can written as
R2:DOF2 = μ medium (275) ^ μ large (15) = 0.75 ^ 0.15 = 0.15.
Contributes Low to cutting speed and Medium to feed rate.
R3:DOF3 = μ hard (275) ^ μ medium (15) = 0.25 ^ 0.85 = 0.25.
Contributes Very Low to cutting speed and Slow to feed rate.
R4:DOF4 = μ hard (275) ^ μ large (15) = 0.25 ^ 0.15 = 0.15.
Contributes Very Low to cutting speed and Medium to feed rate. The fuzzy outputs *μ (v)* and *μ (f)* are the union (max) of these four contributions for each parameter; that is the next step.

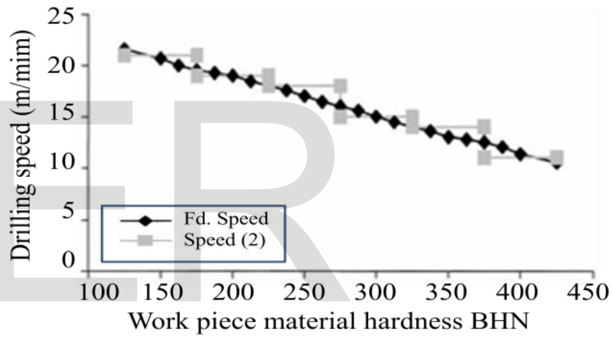


Fig. 6. Fuzzy drilling speed (Fd) for carbon steels,

In the Machining Data Handbook, a range of work piece material hardness is grouped together for which a single speed value is assigned. But, when the fuzzy theory has been applied to calculate the speed it predicts gradually Work-piece material hardness is represented on the x-axis and the fuzzy drilling speed is represented on the y-axis. As can be seen from these Figures that the fuzzy drilling speed values lie closely to the recommended drilling data suggested in machining data handbook [11], showing very good correlation and representation.

For selecting drilling speeds for different types of work materials, it is feasible to use one standard model rather than designing separate specific model for each material. Decreasing values of the work piece material hardness (BHN) values change. Thus, speed-values for different work-piece material hardness can be represented by a continuous line which appears very close to a straight line, thus making it easier for the user to select the speed value for a specific work-piece material hardness for the drilling operation.

IX. CONCLUSIONS

- Fuzzy logic for optimum selection of drilling machine parameters is presented in this paper.
- To described and evaluate the relationship between a given work piece material hardness and drilling speed by using fuzzy set theory.
- To control the drilling process has become essential particularly in sectors such as the aerospace industry where precision drilling holes must be strictly controlled.
- A work piece having different types of hardness values for evaluating drilling parameters a standard fuzzy model can be used.

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