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Application of Fuzzy Logic for Grinding Conditions

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ABSTRACT

This paper has presented an application of an optimum grinding conditions based on the fuzzy logic. Fuzzy logic can handle vague and uncertain knowledge, and presents a scheme for integrating data with various kinds of grinding data. Especially, this research is capable of determining the grinding conditions taking into account some fuzzy membership function represented for trapezoidal form such as hardness and surface roughness of workpiece, material tensile strength and elongation, and requirement of grinding method.

Larsen's fuzzy production method utilizing the fuzzy production rule can be applied on the establishment of grinding conditions, and also the output value obtained by the center of gravity method can effectively utilize the optimum grinding conditions.

Key Words : Fuzzy logic, Fuzzy production rule, Optimum grinding conditions, Larsen's fuzzy production method, Fuzzy membership function

1. Introduction

Grinding operation is considered as a very effective machining technology to attain a high production rate and a good surface quality of components. However, grinding operations still need the skill and experience of an operator because of the lack of scientific system[1,2] for machining which deals with domain knowledge to solve this problem.

To cope with ambiguous and qualitative grinding knowledge, this paper utilized the fuzzy logic based upon fuzzy sets[3,4] when establishing the grinding conditions. Therefore, this paper tries to establish the grinding conditions utilizing the fuzzy production rule.

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2. Fuzzy production rule

Improvement of grinding operations for a precision machining has been achieved by solving the problems of such complex factors[5], chatter vibration[6], grinding burn[7], wheel wear[8], and so on. In general, the object of grinding operations is to produce a workpiece with a good surface quality with a minimum time and/or maximum material removal rates. However, since grinding operations are affected by various unexpected factors during the process, it is not easily achieved the object. Since the fuzzy logic is an instrument for solving this problem, it tries to develop an human thinking which is relied upon the fuzzy logic.

A fuzzy production rule is denoted as a fuzzy relationship described as a fuzzy logic. In a fuzzy set[4], there are amount of ways in which a fuzzy logic may be defined. The selection of a fuzzy membership function reflects on not only the intuitive but also the effect of connective criterion. Since the choice of a fuzzy function involves a number of criterion by means of a characteristics and degree of freedom of data, these properties are justified on purely intuitive ground, therefore, this gives us a more flexible criterion for choosing the grinding conditions. Furthermore, as a field of fuzzy logic, it is necessary to consider the fuzzy logic associated with each fuzzy membership function before the application of fuzziness.

Fuzzy production rule can realize the architecture of grinding conditions, which may request the human thinking because treatment of knowledge can be described by membership functions based upon a fuzzy set.

Fukami, Mizuno, and Tanaka[9] have proposed a set of intuitive criteria for choosing a fuzzy function that constraints a relationship between the antecedents and the consequents of a conditional proposition, with the latter playing the role of a premise in approximate reasoning.

In this paper, fuzzy inference at the establishment of grinding condition is implemented as follows: Now, if X and Y as a fuzzy set give a composition of fuzzy relationship (R), it can be denoted as a fuzzy sets: That is, it is described to $\mathbf{X}\times\mathbf{Y}=[(x,y)|x\in\mathbf{X},\ y\in\mathbf{Y}]$. Therefore, fuzzy membership function, μ_R is given as

$$\mu_R: \mathbf{X}\times\mathbf{Y} \rightarrow [0,1] \qquad (1)$$

In equation (1), the fuzzy sets, X and Y are

$$X=\{x_1, x_2, ..., x_m\}$$
$$Y=\{y_1, y_2, ..., y_n\} \qquad (2)$$

Also, as grinding conditions are established by the fuzzy inference denoted as a fuzzy matrix, the fuzzy relationship (R) is represented as a [m×n] matrix.

$$R=\left|\begin{array}{c} \mu_R(x_1, y_1)\cdots \mu_R(x_1, y_n) \\ \mu_R(x_2, y_1)\cdots \mu_R(x_2, y_n) \\ \cdots \\ \mu_R(x_m, y_1)\cdots \mu_R(x_m, y_n) \end{array}\right| \qquad (3)$$

Where, if it can denote that fuzzy relationship, **R** is **X×Y**, and another fuzzy relationship, **S** is Y×Z, the fuzzy composition **R·S** is denoted to

$$\mathbf{R\cdot S} \leftarrow \rightarrow \mu_{R\cdot S}(x,z)=\vee\{\mu_R(x,y)\wedge\mu_S(y,z)\} \qquad (4)$$

It is generally denoted that the equation (4) is called the composition of '*min-max*'. Where, in the equation (4), *min-max* means the minimum and maximum value to the fuzzy membership function, respectively.

As it is well known, there are two fuzzy inference rules approximately. In this case, the procedural steps of fuzzy inference is realized as follows:

Premise 1 ***IF*** x is A ***THEN*** y is B
Premise 2 ***IF*** x is A'
→
---------------------- (5)
Consequence y is B'

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Premise 2 ***IF*** x is B'
→
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Where, x and y mean the element of subject, and A, A' and B, B' are fuzzy predicates. Furthermore, if it suggests that 'A→ B' is denoted as a fuzzy relationship, it is inferred as follow:

A→ B ⋯ R (fuzzy relationship)
A'
----------------------- (7)
→ B

Therefore, it can denote that equation (7) can be transformed into

$$B'=A'\cdot R=\vee\{\mu_{R'}(X)\in(X, Y)\}$$
$$(A, A'\in X,\ B, B'\in Y) \qquad (8)$$

where, this equation (8) becomes the inference type on the fuzzy production rule, and it can be obtained from research papers, *enquete* results, several text, and so on.

3. Composition of fuzzy membership functions and Larsen's production rule

Fuzzy logic has been successfully used in the establishment of machining conditions[4,10]. The grinding conditions are established from the qualitative and ambiguous knowledge obtained from skilled hands as well as the several papers, *enquete* results, and so on.

The fuzzy reasoning based on the use of Larsen's production rule as an implication of the inferred consequence, C_i, in equation (9).

$$\mu_{ci}(w_i) = \max \mu_{ci*}(w_i), \quad (i=1, \ldots, 4) \tag{9}$$

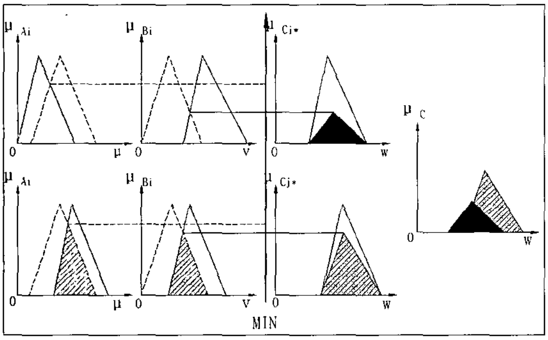

Fig. 1 Fuzzy production rule by Larsen's method

Figure 1 shows a graphic interpretation of the Lemma in terms of Larsen's method. In figure 1, part C_i with the white areas(i=1, ..., 4) are the data accumulated in the knowledge for grinding operations. That is, *i=1* means that surface roughness is normal and workpiece hardness is soft, *i=2* means that surface roughness is normal and workpiece hardness is middle, *i=3* means that surface roughness is rough and workpiece hardness is soft, and *i=4* means that surface roughness is rough and workpiece hardness is middle.

The output value obtained from the equation (9) becomes a constant value transformed as a non fuzzy number. The widely used the center of area method generates a center of gravity of the possibility distribution of a control action.

In order to utilize the Larsen's fuzzy membership method for fuzzy logic, it is necessary to composite to fuzzy membership function given in grinding knowledge. Thus, the meaning of the numbers is like the characters expressed in the form of "*width_B X_min Center width_A X_min*" as shown in figure 2.

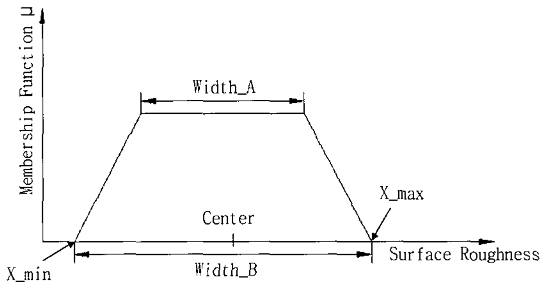

Fig. 2 Fuzzy form represented of trapezoidal type

In figure 2, if the *width_A* has a value of zero, the fuzzy numbers are represented as a triangular fuzzy membership function. In a similar way, figure 3 shows the fuzzy membership function for the hardness of workpiece and surface roughness, and also figure 4 and 5 show the fuzzy membership function for elongation and tensile strength of workpiece, respectively.

This paper suggests the fuzzy logic based on fuzzy sets which is effectively able to cope with the grinding data in case of establishment of grinding conditions.

4. Establishment of the grinding conditions by fuzzy production rule

Fig. 6 indicates the reasoning process using the fuzzy production rule by Larsen's method at the establishment of grinding workpiece velocity. In this case, if constraint of pre-positions are SUJ2(workpiece), cylindrical plunge grinding, and soluble type(coolant), decision of wheel velocity is derived with the required surface roughness as well as the hardness and heat treatment of workpiece.

Figure 6 shows a schematic diagram for establishment of grinding workpiece velocity utilizing a fuzzy production rule. This method can calculate the output of the workpiece velocity(V_w) given in the following equation (10):

$$\mu_{ci}(V_{wi}) = \max \mu_{ci*}(V_{wi}), \quad (i=1, \ldots, 4) \tag{10}$$

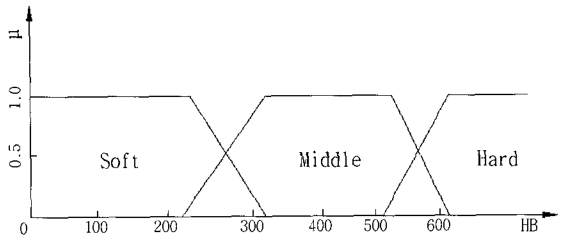

Fig. 3 Fuzzy membership function for the hardness of workpiece and surface roughness

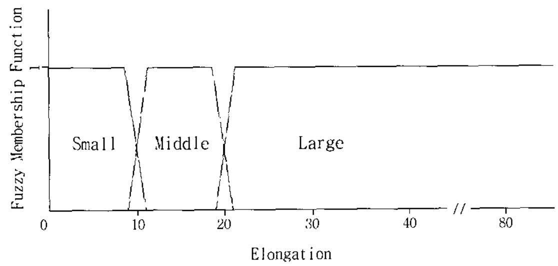

Fig. 4 Fuzzy membership function for the elongation of workpiece

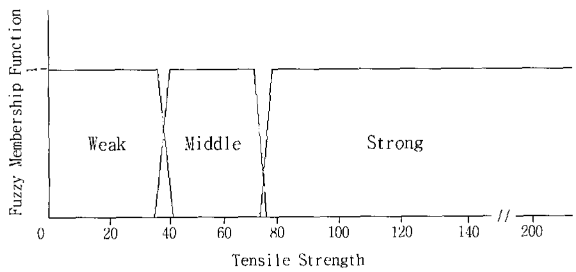

Fig. 5 Fuzzy membership function for the tensile stress of workpiece

The output value, V_w, obtained from the equation (10) becomes a constant value transformed as a non fuzzy number. In case of a discrete universe, this method yields the following equation (11).

$$V_{wi0}=[\sum \mu_c(V_{wi})\cdot V_{wi}\cdot dV_{wi}]/\sum \mu_c(V_{wi})\cdot dV_{wi}] \quad (11)$$

Thus, according to the center of area method, this fuzzy production rule can result in workpiece velocity.

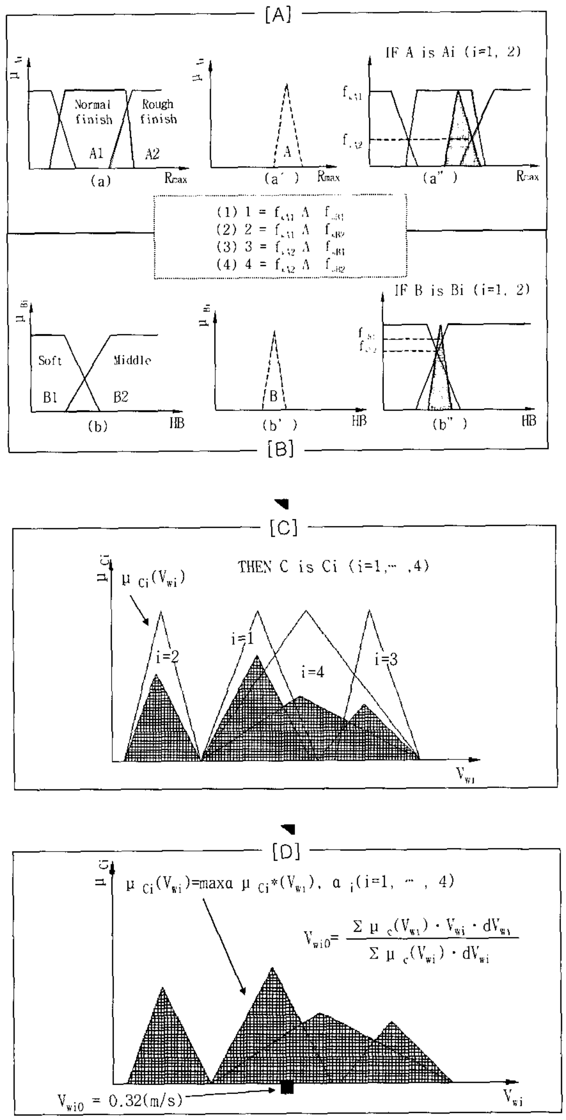

Fig. 6 Schematic diagram for establishment of grinding workpiece velocity utilizing a fuzzy production rule.

Therefore, the workpiece velocity is determined as follow: A_i, $B_i(i=1,2)$ and $C_i(i=1, ..., 4)$ are maximum surface roughness, brinell hardness, and workpiece velocity, and it is possible to denote the fuzzy sets on the product parameters described as a membership function. The membership function formulated to triangular are represented in $\mu_{Ai}(R_{max})$, $\mu_{Bi}(HB)$, and $\mu_{Ci}(V_{wi})$. Also, if the ambiguous states represented function are defined as a fuzzy set **A** and **B**, these membership functions are defined as the $\mu_A(R_{max})$ and $\mu_B(HB)$, respectively.

The degree of fitting, represented as a symbol f, on the fuzzy production model defined as (**A&A**$_i$) and (**B&B**$_i$), i.e., the matching process between input constraints (**A&A**$_i$) and knowledge-base (**B&B**$_i$), is calculated as:

$$f_{wA1}=\{\mu_{A1}(R_{max})\wedge\mu_A(R_{max})\}=1.0$$
$$f_{wA2}=\{\mu_{A2}(R_{max})\wedge\mu_A(R_{max})\}=0.44$$
$$f_{wB1}=\{\mu_{B1}(HB)\wedge\mu_B(HB)\}=0.82$$
$$f_{wB1}=\{\mu_{B1}(HB)\wedge\mu_B(HB)\}=0.67 \quad (12)$$

Fuzzy composition, $\boldsymbol{w}$, with respect to the of fitting on the antecedent can be represented as:

$$w1=f_{wA1}\wedge f_{wB1}=(1.0)\wedge(0.82)=f_{wB1}=0.82$$
$$w2=f_{wA1}\wedge f_{wB2}=(1.0)\wedge(0.67)=f_{wB2}=0.67$$
$$w3=f_{wA2}\wedge f_{wB1}=(0.44)\wedge(0.82)=f_{wA2}=0.44$$
$$w4=f_{wA2}\wedge f_{wB2}=(0.44)\wedge(0.67)=f_{wA2}=0.44 \quad (13)$$

If the priority of fuzzy production rule is dependent on the degree of weight, it is denoted as follow.

$$\mu_{ci}*(V_{wi})=\alpha_i\cdot w_i\cdot\mu_{ci}(V_{wi}),$$
$$\alpha_i(i=1,\ ...,\ 4)=1.0 \quad (14)$$

By means of these steps, it can be calculated the output denoted by fuzzy membership function.

$$\mu_{ci}(V_{wi})=\max\alpha\ \mu_{ci}*(V_{wi}),$$
$$(i=1,\ ...,\ 4) \quad (15)$$

The output value obtained from the figure 6[D] means the fuzzy set of membership function. The widely used center of area strategy generates the center of gravity of the possibility distribution of a control action. Therefore, it can obtain the workpiece velocity through the equation (11) by fuzzy production rule. In this case the workpiece velocity for cylindrical plunge grinding, soluble type coolant, workpiece SUJ2, and surface roughness 5μm is 0.32 m/s.

Table 1 A part of LISP program for establishing the workpiece velocity by fuzzy production rule

```
(defrulset workpiece velocity-1)
  (defrule (workpiece velocity-1 rule-1)
    (frame temporary frame ? (grinding type
is cylindrical plunge)
                    (workpiece is SUJ2) ))
    (frame (workpiece hardness ? (hard
middle soft) ))
    (frame (surface roughness ?
(ultra-precision precision fine normal
rough) ))
  (bind ? normalizing with normal finish)
  ......
  (call (write_figure_data "workpiece data"
    0.208 0.0 0.04 0.168 0.248 ? SUJ2 with
normal finish) )
  (halt)
  )
```

Moreover, an important point in the case of utilizing a fuzzy production rule is the representation of fuzzy membership function. Table 1 shows a part of calculation of workpiece velocity by Larsen's fuzzy production method represented of LISP computer language.

In table 1, the character "*0.208 0.0 0.04 0.168 0.248*" are represented with, fuzzy membership function in figure 2, "*width_B, X_min, Center, width_A, X_min*", respectively.

Thus, according to the center of area method, this fuzzy production rule can obtain workpiece velocity.

5. Conclusions

This paper has presented an application of grinding conditions based on the fuzzy set theory. In order to deal with uncertain and qualitative grinding knowledge, it designs on the grinding conditions to cylindrical grinding utilizing a fuzzy production rule based on a fuzzy logic. Obtained results are as follow:

(1) This research is capable of determining the grinding conditions taking into account some fuzzy membership function represented for trapezoidal form such as hardness and surface roughness of workpiece, material tensile strength and elongation, and

requirement of grinding method.

(2) Larsen's fuzzy production method utilizing the fuzzy production rule can be applied on the establishment of a grinding conditions.

(3) The output value obtained by the center of gravity method can effectively utilize the optimum grinding conditions.

(4) This paper suggests the fuzzy logic based on fuzzy sets which is effectively able to apply the grinding data in case of representing the ambiguous and qualitative knowledge.

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