Modeling Ultrasonic Machining Process using Fuzzy Inference System

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***Abstract*— This paper deals with the modelling the ultrasonic machining process by using the rules of fuzzy inference system. Experiments have been conducted at different levels of amplitude and pressure and output in terms of material removal rate was measured. In the fuzzy inference system the parameters such as the weight are determined to minimize the difference between the prescribed value and the output of the system. However, the output of the system also depends on the shape of the membership function. The results of the predictive model are in the close agreement with the experimental values.**

***Keywords*— FIS, Membership Function, Ultrasonic Machining, MRR, Amplitude**

I. INTRODUCTION

The fuzzy inference system has been applied to the wide area of engineering such as the automatic control and the decision support system because of the better performance than the conventional methods [l]. Several non-traditional machining processes such as laser cutting, water-jet cutting, ultrasonic cutting, electro discharge machining, etc., have been developed for application on FRPs for machining holes due to the anisotropic and inhomogeneous structure of FRPs [2]. Fuzzy AHP method of decision making was compared with expert system using Fuzzy inference system [3]. FIS provides a humanlike approach to solve vendor rating problems [4]. The vibration drilling technique has attracted extensive interest in recent years. Both the theoretical investigations and experimental results have indicated that the machining quality of the drilled holes can be improved, as well as the thrust force being reduced by means of vibration drilling metals [5–8]. In the fuzzy inference, the system is usually realized as the if-then rules which include a set of membership function in the antecedent and the weight in each rule.

II. OVERVIEW OF FUZZY INFERENCE SYSTEM (FIS)

Many times we know about thumb rules of result applied to any process for the given input. It is because unavailability of precise input available data. Therefore, we thought that fuzzy logic concepts could better represents the cognitive processes of the specialists.

The primary function of the fuzzy-rule based inference system is to establish a mapping from inputs to outputs. However, this mapping mechanism is not built on any precisely defined analytical or numerical function. Instead, it is constructed on human knowledge: As experience and intuitions are often represented in the form of (IF…THEN…) rules, it works just like an expert who reasons and inferences by using knowledge available to him or her. It is therefore called an inference engine that applies knowledge on the inputs and derives solutions as outputs. Figure 1 shows a block diagram of a FIS.

Fuzzy inference system consists of:

1. Fuzzification interface,
2. Rule base
3. Data base
4. Decision-making unit, and
5. Defuzzification interface.

A FIS is described in figure as:

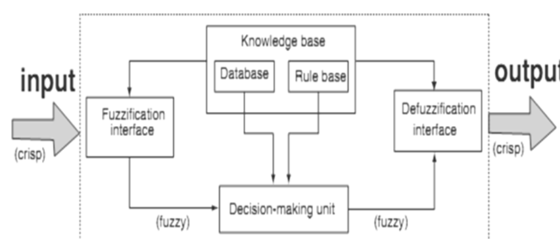

Fig. 1 Block Diagram of FIS

- A rule base contains number of fuzzy If-Then rules;
- A database which defines the membership functions of the fuzzy sets used in the fuzzy rules;
- A decision-making unit which performs the inference operations on the rules;
- A fuzzification interface which transforms the crisp inputs into degrees of match with linguistic values; and
- A Defuzzification interface which transforms the fuzzy results of the inference into a crisp output.

The core of the inference engine is its knowledge, which is represented in the form of "if-then" rules. The fuzzy-rule base for the supplier performance assessment consists of a group of “if-then” rules with two inputs representing the two input process variables amplitude and pressure and output representing the material removal rate (MRR).

Mamdani’s fuzzy implication rule has been used for the inference logic. Basically, when the inference engine receives a set of inputs. All the rules may be activated or fired to a certain degree, and they produce individual outputs accordingly. The individual outputs are combined together using “minimum-maximum” logic operation to produce the aggregated single fuzzy output. Finally, the fuzzy output is to be defuzzified to generate a digital or crisp output.

The variables as the system’s inputs are to be fuzzified for the fuzzy inference engine to work on them. Before fuzzification, the suppliers’ variables are just crisp numerical data carrying no linguistic value. Fuzzification involves assigning a set of predefined fuzzy membership functions to them so that the data are transformed into a set of meaningful observations for fuzzy inference engine.

The FIS works as follows:

The crisp input is converted in to fuzzy by using fuzzification method. After fuzzification the rule base is formed. The rule base and the database are jointly referred to as the knowledge base. Defuzzification is used to convert fuzzy value to the real world value (crisp value) which is the output.

The steps of fuzzy reasoning (inference operations upon fuzzy IF–THEN rules) performed by FISs are:

1. Compare the input variables with the membership functions on the antecedent part to obtain the membership values of each linguistic label. (This step is often called fuzzification.)
2. Combine (through a specific t-norm operator, usually multiplication or min) the membership values on the premise part to get firing strength (weight) of each rule.
3. Generate the qualified consequents (either fuzzy or crisp) or each rule depending on the firing strength.
4. Aggregate the qualified consequents to produce a crisp output. (This step is called defuzzification.)

The most important two types of fuzzy inference method are Mamdani’s fuzzy inference method, which is the most commonly seen inference method. This method was introduced by Mamdani and Assilian (1975). Another well-known inference method is the so-called Sugeno or Takagi–Sugeno–Kang method of fuzzy inference process. This method was introduced by Sugeno (1985). This method is also called as TS method. The main difference between the two methods lies in the consequent of fuzzy rules. Mamdani fuzzy systems use fuzzy sets as rule consequent whereas TS fuzzy systems employ linear functions of input variables as rule consequent. All the existing results on fuzzy systems as universal approximators deal with Mamdani fuzzy systems only and no result is available for TS fuzzy systems with linear rule consequent.

Fuzzy rules are a collection of linguistic statements that describe how the FIS should make a decision regarding classifying an input or controlling an output. Fuzzy rules are always written in the following form:

if (input 1 is membership function 1) and/or (input 2 is membership function 2) and/or... then (output n is output membership function n).

The purpose of fuzzification is to map the inputs from a set of sensors (or features of those sensors such as amplitude or spectrum) to values from 0 to 1 using a set of input membership functions.

The consequence of a fuzzy rule is computed using two steps:

1. Computing the rule strength by combining the fuzzified inputs using the fuzzy combination process.
2. Clipping the output membership function at the rule strength.

The outputs of all of the fuzzy rules must now be combined to obtain one fuzzy output distribution.

In many instances, it is desired to come up with a single crisp output from an FIS. This crisp number is obtained in a process known as defuzzification.

III. THE PROPOSED METHODOLOGY USING FIS

The above described method may summarize by following steps.

1. Determine the set of variables.
2. Determine the objective, alternative and criteria.
3. Identify the input and output variables.
4. Propose membership functions for input and output variables.
5. Propose rules to determine the relations between inputs and outputs.
6. Select an appropriate inference mechanism.
7. Placement of alternatives corresponding to each criterion.
8. Extract the evaluation result by the MATLAB software.

IV. CASE STUDY

Here, we illustrate the proposed system in manufacturing industry for Ultrasonic machine producing holes in the polymer composite product. We analyze using the input variable as Amplitude and Pressure and output variable is Material Removal Rate (MRR).

The proposed inference system applies triangular and trapezoidal membership functions to define the shape of both input and output variables. These curves, used for defining the fuzzy sets, have the advantages of simplicity these are shown below.

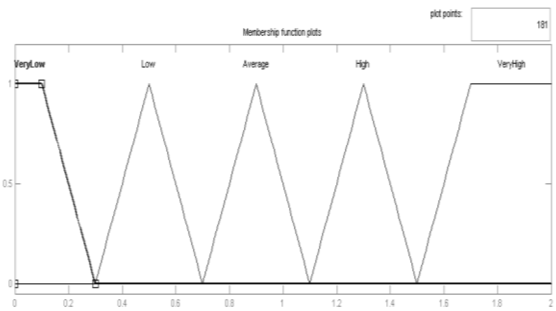

Fig.2. Amplitude Membership function

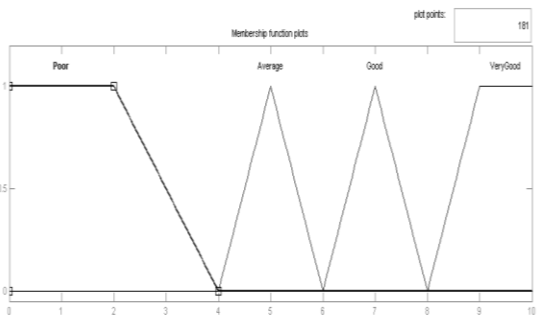

Fig.3. Pressure Membership function

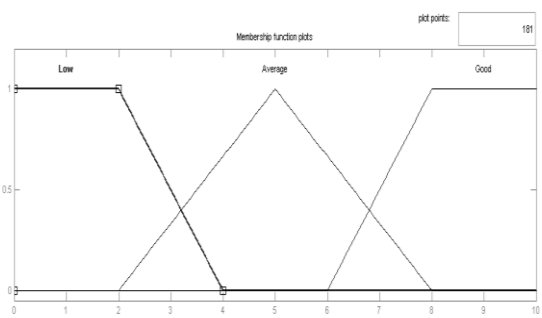

Fig.4. Output 'MRR' Membership function

By discussing with the production manager and other key personnel 21 rules are derived by considering two criteria.

Some of the sample rules are as follows:

1. If (Amplitude is Very Low) and (Pressure is Very Low) then (MRR is Very Low)
2. If (Amplitude is Low) and (Pressure is Low) then (MRR is Low)
3. If (Amplitude is High) and (Pressure is Low) then (MRR is High)
4. If (Amplitude is High) and (Pressure is High) then (MRR is High)
5. If (Amplitude is Very High) and (Pressure is Very High) then (MRR is Very High)

A. Result

Fig. 5 shows the rule viewer of the FIS for the linguistic descriptions and the corresponding membership values for one sample corresponding to the given variables. In this figure, a set of rules is shown for the performance evaluation. The input variables for one sample, the corresponding output score are presented. Similarly, the performance scores for other samples are computed using FIS.

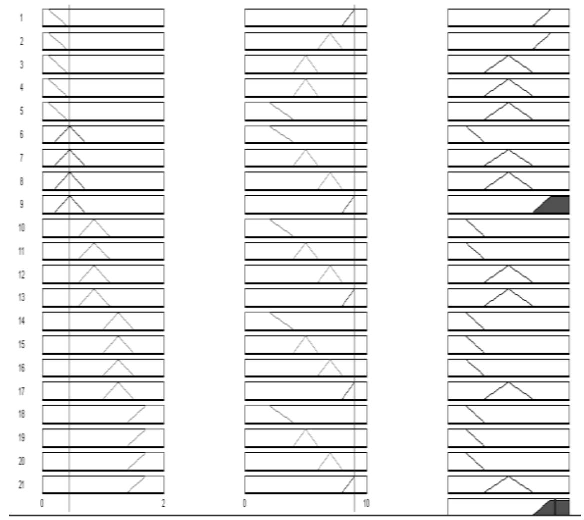

Fig.5. Rule viewer and result of one sample

Figure 6 shows one of the output surfaces of the FIS. Two input variables, namely Amplitude and Pressure vary (0 to 2), and (0 to 10), respectively. Once the knowledge base is prepared and stored in the FIS in the form of rule base, it become easier to forecast the performance score (MRR) for any combination of input variables.

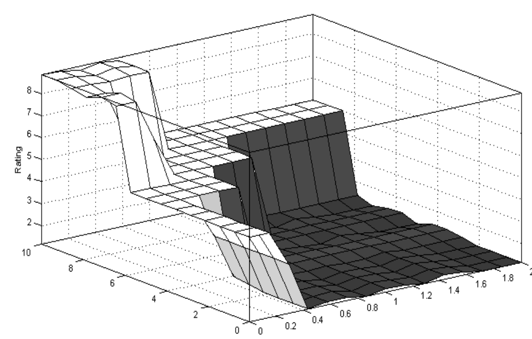

Fig.6. Surface viewer (3-D result of one sample)

V. CONCLUSIONS

Considering the results of the proposed system, it can say that the FIS approach provides a more humanlike decision making to approach problems and it is also found that the reasoning of the system was nearer to an expert's reasoning process.

For the simplicity of presentation and illustration of the complex methodology, only a two variable case has been considered in this paper. Fairly large variables can also be undertaken and the proposed methodology may offer consistent performance in these cases too.

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