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Fuzzy Logic Based Optimization Method for Mechanical Systems and its Application

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Abstract

This paper proposes a method to optimize the thermal barrier coating thickness which has applications in Internal Combustion engine. Fuzzy logic was used to find the optimal value of coating thickness by applying Zadehs principle. This paper also discusses various steps used in the search for an elusive solution. The key steps used in this paper include fuzzification, defuzzification, and interpretation of the solution. A flow chart was developed to optimize the coating thickness. It also discusses the construction of a triangular membership structure and the interpolation function of LaGrange to explain the Fuzzy logic.

1 Introduction

Fuzzy logic is used in problems where the mathematical model information is uncertain, or model reconstruction is impossible. The fuzzy theory is required to explain unspecified phenomena that can't be described using classical logic. This allows the device response to external factors to be identified,

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assuming input data is fuzzed and the mathematical model adopted is uncertain. Fuzzy logic also allows the most appropriate solution to be derived from the obtained results. The method used in fuzzy theory is described with an overview of its advantages and disadvantages as the concept of extension. It also provides the way to choose the most reliable solution based on approximation theory.

2 Application Of Zadeh's Extension Principle

The process of assigning a fuzzy number input with a certain degree of membership is known as Fuzzification. This degree can be anywhere between the interval [0,1]. Larger values denote higher degrees of set membership. Such a function is called membership function and is denoted by $A : X \to [0, 1]$. Each Fuzzy set is defined entirely and uniquely by a certain membership function. Figure 1 shows a Fuzzy set A, which is defined as a set of X space elements which indicates a certain membership to set 1. In this, the value x varies between 0 and 1.

$$A = \{x, \mu_A(x) : x \in X\},\ \mu_A : x \to [0, 1]$$

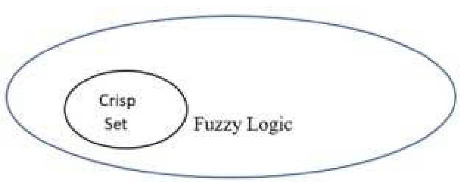

Figure 1: Relation between crisp data and fuzzy set.

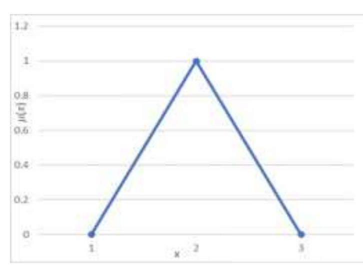

Figure 2: Triangular Membership Function of x from 1 to 3.

A fuzzy rule generally takes the form R : IF X is A, THEN y is B, where A and B are linguistic values defined by fuzzy sets. The rule is also known as fuzzy implication or fuzzy conditional statement. The Fuzzy rule is sometimes abbreviated as $R : A \to B$. The expression describes essentially a relationship between two variables X and Y. This suggests that a fuzzy rule can be defined as a binary relation R on the product space $X \times Y$.

In order to fuzzify the above function, creation of the membership function is important. The membership function can be either triangular or trapezoidal. The figure 2 gives the formation of triangular membership function. From figure 2, we can infer that $\mu_A : X \rightarrow [0, 1]$. By the triangular function the maximum value is 1 for a particular value of x. In most of the cases the point at which $x = 1$ is the average of the two end points. Since there is an endless number of approaches to characterize fuzziness, there is an infinite number of approaches to graphically delineate the membership functions that describe this fuzziness. The choice of which method to use depends entirely on the size of the problem and the type of problem. It is also very important to set the interval and the number of membership functions instead of choosing the shape of the membership function. The only condition that the membership function really must satisfy is that it must vary between 0 and 1. The function itself can be an arbitrary curve whose form is suitable based on simplicity, ease, speed, and efficiency. Therefore, the type of membership function does not play a crucial role in shaping the performance of the model.

3 Data Processing and Fuzzy Optimization

A study of the above given strategy was completed on piston coating. Here we are comparing the performance characteristics of coated and uncoated piston. We have coated an insulation on the piston by varying the thickness from $125\mu m$, $300\mu m$,$450\mu m$,$500\mu m$,$800\mu m$ & $1000\mu m$. With each thickness heat flux and temperature variation was found in ANSYS. The intermediate value of thickness was found by interpolation, which was explained earlier. The optimal value of thickness at which maximum performance is obtained is found by Fuzzy optimization as shown in figure 3. These optimization steps are done in MATLAB.

By optimizing thickness, we can optimize the material usage and thereby decrease the material usage. This will in turn reduce the cost of production. If the thickness of the insulation increases beyond a value, then the clearance required for compression reduces. The insulation thickness determines the amount of heat transfer through the piston heads. So, the parameters that effect the heat transfer through piston that we consider here are heat flux and temperature. Both the factors have high influence on thickness. As the thickness increases heat flux decreases to a minimum value, whereas in the case of temperature the value increases.

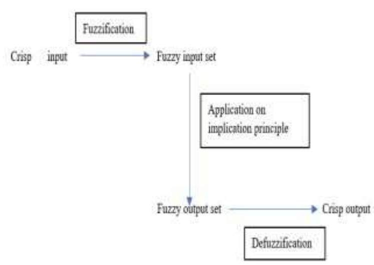

Figure 3: Steps for optimization.

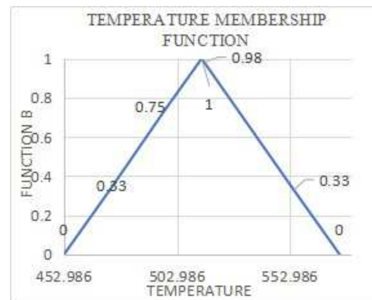

Figure 4: Triangular membership of Temperature.

3.1 Fuzzification of Input Variables

The input variables for any non-linear and complex simulation can be expressed in fuzzy sets [4]. If the mechanism is essentially quantitative or the inputs are extracted from the measurements of the sensor, then these clean numerical inputs could be fuzzified to be used in a fuzzy inference system. Although one can construct fuzzy sets and perform different operations on them, they are usually used mainly while creating fuzzy values and defining the linguistic meanings of fuzzy variables. In the above case, the membership degree associated with A, B & C, where A=Heat flux, B=Temperature & C=Thickness are defined as the membership functions $[A\ B\ C]$, where the functions can be mapped as follows: $\mu_A : A \to [0,1]$, $\mu_B : B \to [0,1]$, $\mu_C : C \to [0,1]$.

These membership degree for fuzzy set $[A\ B\ C]$ are graphically represented by triangular shapes given in figure 4, figure 5 & figure 6 respectively.

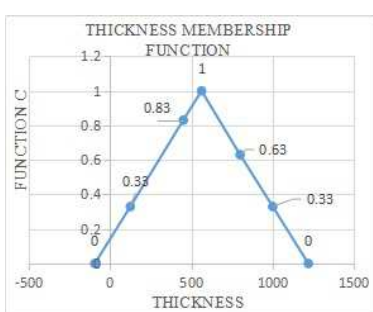

Figure 5: Triangular membership of Thickness.

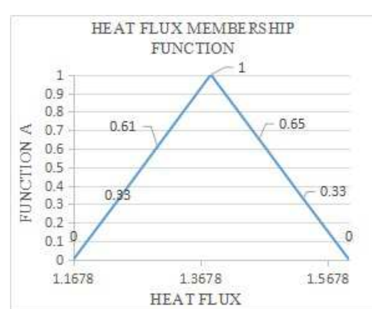

Figure 6: Triangular membership of Heat Flux.

1. Fuzzy implication: Fuzzy relation obtained in this step can be embedded in a single condition fuzzy proposition. Relation R that is embedded in a conditioned fuzzy proposition p of the form; p: IF x is A THEN y is B, where A and B are linguistic values. The rule is also called a fuzzy implication or fuzzy conditional statement. Fuzzy implication is an essential connective in fuzzy control systems because the control strategies are embedded by sets of IF-THEN rules. $R(x, y) = I[A(x), C(y)]$, where I is fuzzy implication. There are different fuzzy implications used in fuzzy application such as Lukasiewicz's, Stochastic, Goguen's and Zadeh's. This implies a fuzzy law can be described as a binary relationship R on the product space $X \times Y$. From the above relation $A(x)$ and $C(y)$ are obtained by applying Lukasiewicz implication;
$$I(A, C) = \min(1, 1 - A + C)$$

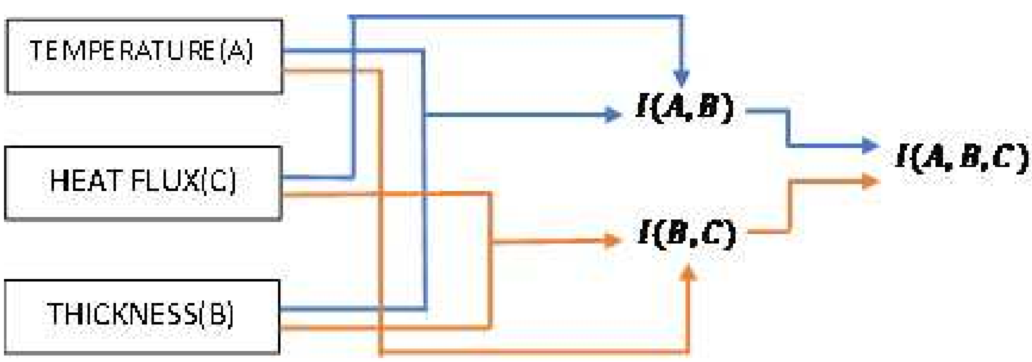

Figure 7: Schematic representation to obtain the combination of three function.

2. Using Zadeh's principle: To the functions A, B and C apply the Zadeh's extension principle. The calculation was done in MATLAB in order to make the steps easier. The obtained result of both the function is in the form of matrix, since it is done in MATLAB.
$$I(A, B) = \max\{1 - A, \min(A, B)\}$$
The application of Zadeh's principle to the function $I(A, C)$ and $I(B, C)$, where C is the thickness which is dependent on heat flux A and temperature B can be explained using the flow chart in figure 7.

3. Defuzzification over fuzzy interval: Defuzzification is the process of reducing a fuzzy set into a crisp set or converting a fuzzy member into a crisp member. It is the method of generating a quantifiable result, given fuzzy sets and corresponding membership degrees, in crisp logic. It is also a method of mapping a fuzzy set into a crisp set. These will have a number of rules which will make a number of variables into a fuzzy outcome; that is, the outcome is known as membership in fuzzy sets. Locate the maximum membership degree from the final resultant fuzzy matrix function. Next is the back substitution of the maximum membership degree from the fuzzy interval. By this we can locate the crisp data from the $A(x)$, $B(x)$ and $C(x)$ function.

4. Interpretation of inference: Now from the final result obtained, the maximum value is selected and its position is noted. From here back substitution is done in order to find out the crisp data from the origin result. From the result obtained the position is again noted and the crisp data is noted down from the initial stage. Hence the main data causing the maximum value is obtained. So, the optimal thickness is obtained from the results [3]. By this we can also obtain heat flux corresponding to the optimal value. The same steps are done for the relation of heat flux and thickness i.e. $\mu(A, B)$ and the same optimal result is obtained.

4 Conclusion

In this paper optimization of thickness was done with respect to parameters such as heat flux and temperature. An algorithm was developed to find the optimal thickness which was illustrated. This can be extended to optimization of several other parameters [1]. Fuzzy logic and rule of inference using Zadehs extension principle was used to obtain various relation functions [2]. Defuzzification step was constructed to obtain optimal value.

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