An intelligent cooling system for the crankshaft grinding using infrared pyrometer sensor via fuzzy logic approach

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Abstract

In this paper an innovated method is used for cooling grinding zone via fuzzy logic using infrared pyrometer for non-touch measuring of the temperature. This method is very reasonable for cooling the grinding zone due to the used fuzzy logic approach which is more realistic in physical realities. The simplicity of the fuzzy rules based on memberships for temperature and the ratio of opening for the coolant outlet valve improved the efficiency of the system with lower loss of the coolant in compare to conventional coolant systems.In this method, the infrared sensor plays a very important role to achieve an accurate and fast cooling process because of its accuracy and rapidity.

Keywords: *Grinding machining, cooling system, Fuzzy logic, infrared pyrometer*.

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Introduction

Heisel (1998) used water for the first time to cool grinding operations; a significant increase on tool life was experienced. From that time, a large variety of coolant fluids have been used for this purpose [1]. Oil-based fluids can be emulsified in water (containing 1 to 20% of oil) or used pure, without any water addition. Using pure oil, mainly because of its lubricating properties, has been a very common procedure. Pure oil better lubricates which drastically reduces the heat due to friction at interfaces and helps to produce better finishing surface. Additionally, grinding force is also reduced, leading to less power consumption for the whole grinding process. This is also one of the main reasons for the use of grinding fluids with lubricating capacity [2]. Furthermore, extreme pressure additives can be applied in order to reduce the possibilities of adhesion at tool-chip interface [3].

Forces and power consumption in low speed machining processes, such as grinding, broaching and tapping are the most influenced by the lubricating properties of the grinding fluid. For these kinds of processes, the temperature at the chip formation zone is relatively low and lubricating properties become more significant. Lower power consumption corresponds to a good lubrication fluid and it is usually the first choice in industry [2].

In contrast, high speed machining processes, such as turning and grinding, produces high temperatures at chip tool interface, which makes the cooling properties more important for a grinding fluid [4, 5, 6].

Recently, minimizing the use of grinding fluid has become a very important issue. Two techniques have been intensively tested: dry grinding, also known as ecological machining, and grinding with a Minimum Quantity of Lubricant (MQL), where a very low amount of fluid is used [7].

The MQL name is given to the process of pulverizing a very small amount of oil (less than 30 ml/h) in a flow of compressed air. Some good results, in terms of tools life, have been obtained with this technique. Braga, et. al. [8] used this technique on grinding. The authors concluded that MQL could reduce the temperature on the chip formation zone, maintaining it at levels low enough to avoid tool material deterioration.

Similarly to grinding, tapping often uses grinding fluids and it is believed to benefit the process in many ways, such as force and temperature reduction and also in improving thread quality [9].

In addition, the application system may significantly affect the temperature at the grinding zone. Tests to define the temperature values and of the heat flow in grinding and tapping processes have been carried out with several methodologies. The use of pyrometer is simple and has a good accuracy to define temperature and heat flow together with analytical mathematical models [10].

In this study we have presented an innovated method based on using fuzzy logic and infrared pyrometer sensor for cooling of a grinding machine. The sensor is a remote sense type and the system cools the grinding surface intelligently without needing to human operator. As a result, not only the cooling process needs less coolant due to the precise operation which is done by the designed surface but also the process will work with higher speed and more efficiency.

2-The structure of cooling system and temperature measurement system

Coolant is necessary to decrease the friction between the work piece and the tool. The type of the coolant, which is mostly mixture of water and soft soap for ordinary steels and gasoline for grinding of cast iron and aleminium, depends on the work piece properties like the type of the alloy, the stiffness and the size.

In the innovated system designed in this study, an electrical pump is used to make the coolant flow to the grinding zone(figure1). By the way, this pump is connected to an electrical valve .The grinding zone temperature is sensed with the infra red pyrometer (figure2), then if the temperature is higher than the safe temperature, the electrical valve will be opened. The opening ratio of the valve is based on the temperature of the grinding zone, which is determined by fuzzy rules explained in section3.

On the other hand the input of the fuzzy cooling system is the grinding zone temperature and the output is the opening ratio of the valve.

Figure.1. Schematic view of a grinding machine with the cooling fluid valve (shown with blue)

Measuring the grinding zone temperature is impossible through touching temperature sensors because of the temperature limitations for safe operating of the heat sensor and also the risk of damaging in contacting with the grinding surface .Consequently; we used an infrared pyrometer (non touching temperature sensor) to measure the grinding zone temperature. The difference between the thermocouples and the pyrometers is that the first ones has to be in touch with the surface and you have to stick it to the surface but the second one can report the temperature remotely and shows it on the screen immediately (Fig.2).

Figure.2. A schematic view of an industrial pyrometer

The pyrometers have vast applicants in different field of industry. As an example in operations like accurate casting, alloy producing control and heat treatments to gain better properties, it is crucial to use pyrometers. They are applicable to use for remote measurements from 7 meters far maximally, and a vast spam from 50 to1800 degree of Celsius in a time less than 50ms.The pyrometer relative error for temperature measuring used in this system is 1%. It measures the temperature by measuring the reflected infrared from the work piece and also calculates the grinding zone temperature in a very short time, less than three seconds (Fig.3).

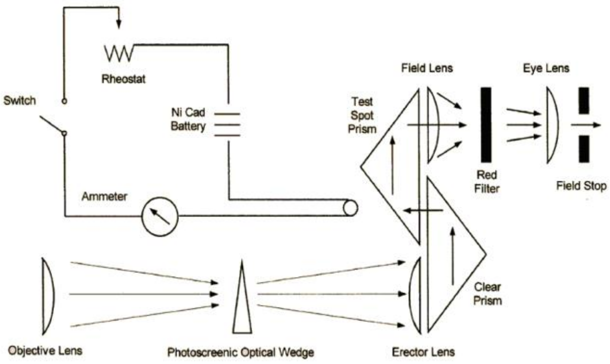

Figure.3. Internal view of an infrared pyrometer

3-Fuzzy Algorithm of the Cooling System

Fuzzy logic was invented by Zadeh in 1965 as an extension of Boolean logic. While classical logic assigns values 1 for "true" and "0" for "false" to a variable, fuzzy logic allows one to assign any values in the interval [0, 1] to a variable. This extension is motivated by the observation that humans often think and communicate in a vague and uncertain way, partly because of insufficient information, and partly due to the nature of the human brain [11].

Fuzzy logic approach can help engineers and researchers to tackle on uncertainty, and to handle imprecise information in a complex situation [12]. During the recent years, the successful application of fuzzy logic for solving complex problems subjected to uncertainty has greatly increased and today fuzzy logic plays an important role in various engineering disciplines [13].

The advantages of the fuzzy approach which is based on fuzzy logic are listed below [14]:

- *Fuzzy logic is conceptually easy to understand.*
- *Mathematical concepts behind fuzzy reasoning are very simple. Fuzzy logic is a more intuitive approach without far-reaching complexity.*
- *Fuzzy logic is flexible.*
- *With any given system, it is easy to layer on more functionality without starting again from scratch.*
- *Fuzzy logic is tolerant of imprecise data.*
- *Everything is imprecise if you look closely enough, but more than that, most things are imprecise even on careful inspection. Fuzzy reasoning builds this understanding into the process rather than tacking it onto the end.*
- *Fuzzy logic can model nonlinear functions of arbitrary complexity.*
- *One can create a fuzzy system to match any set of input-output data. This process is made particularly easy by adaptive techniques like Adaptive Neuro-Fuzzy Inference Systems (ANFIS) or the Local Linear Neuro- Fuzzy (LLNF), which is used in this study.*
- *Fuzzy logic can be built on top of the experience of experts.*
- *In direct contrast to neural networks, which take training data and generate opaque, impenetrable models, fuzzy logic lets to rely on the experience of interpreters who already understand the system. Thus incorporation of expert partial knowledge in combination with learning from examples becomes possible.*
- *Fuzzy logic is based on linguistic labels and implements computing with words*

In this study, the fuzzy linguistic labels used for input are :

1. *Much less temperature*
2. *Less temperature*
3. *Great temperature*
4. *Greater temperature*

Also the below fuzzy linguistic labels are used for output fuzzification:

1- Much less opening 2- Less opening
3- Great opening 4-Greater opening

To find the optimized fuzzy membership function (M.F.), different kinds of MF were investigated *using the measured temperature and considering the safe span of the temperature .*

The investigations showed that the below fuzzy rules are suitable to use for Temperature controller system with the least sum square error for the output:

Rule 1-If T is Much less (mf_1) then open the valve Much less (mf1)

Rule 2- If T is Less (mf_2) then open the valve Less (mf2)

Rule 3- If T is Great (mf_3) then open the valve Great (mf3)

Rule 4- If T is Greater (mf_4) then open the valve Greater (mf4)

The above rules can be written generally as: If T€mf_i then V€ mf_j , where mf_i is the membership function of the i'th linguistic label for input and mfj is the membership function of the j'th linguistic label for output.

These rules were applied in FIS (Fuzzy Interface System) rule editor in Matlab software fuzzy toolbox (Fig.4).

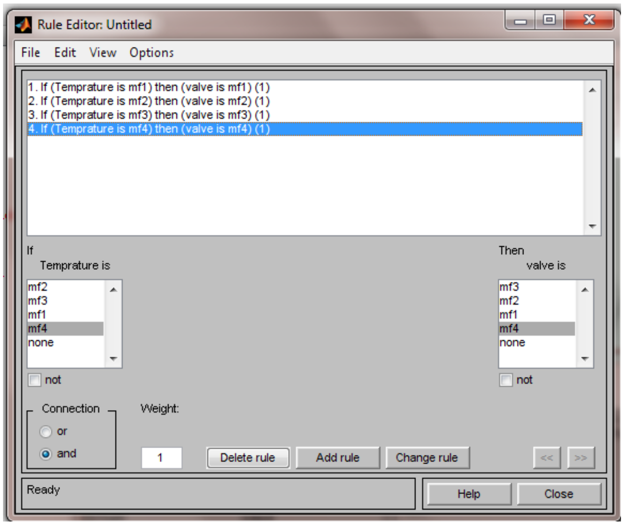

Figure4. Design of four fuzzy rules for intelligent cooling system via Matlab software

In practiced,different kinds of fuzzy membership functions(MF) are common. In this research, different MFs were tested and it was concluded that sigma functions to determine the input (T) and Triangular membership functions(trimf) to determine the output (the opening ratio of the valve) are the optimized MFs.

As the used work piece is melted at 1660 degree of Celsius then T domain was divided to four different domains:

1-mf1: 0-400 degree of Celsius known as Much less temperature

2-mf2:400-800 degree of Celsius known as Less temperature

3-mf3:800-1200 degree of Celsius known as Great temperature

4-mf4:1200-1600 degree of Celsius known as Greater temperature

The membership functions used for four these four domains are shown in Fig. 5.

As shown in Fig.5, the horizontal axis is the temperature value and the vertical axis is the membership degrees.

The same, we have four outputs:

1-mf1: for Much less temperature

2-mf2: for Less temperature

3-mf3: for Great temperature

4-mf4: for Greater temperature

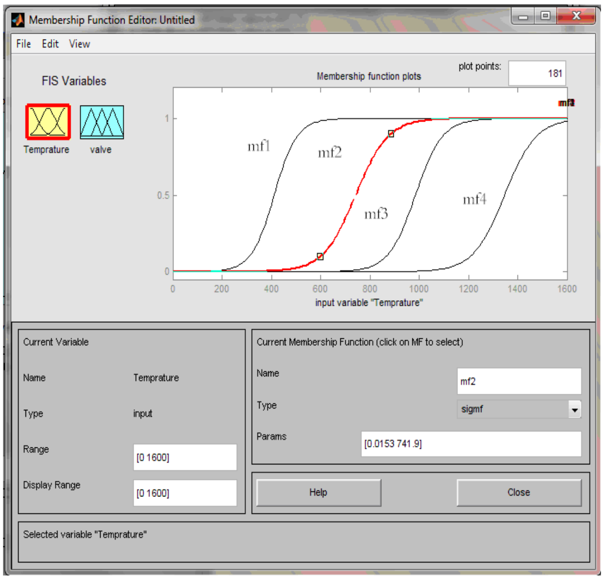

Figure.5. Four input membership functions designed via Matlab software

In the output diagram which is shown in Fig.6 the horizontal axis shows the ratio of opening for the electrical valve and the vertical one shows membership degrees.

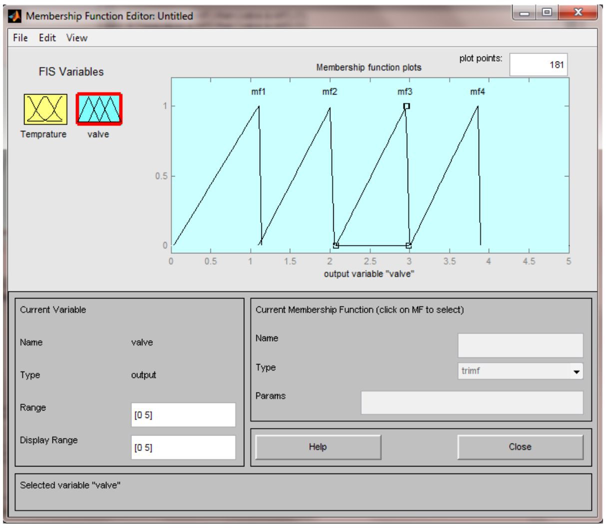

Figure. 6. Four designed output membership functions via Matlab software.

Using these fuzzy diagrams (Figs 5,6) and the mentioned if-then fuzzy rules(rules1-4),the intelligent system input the measured temprature as T and calculates how many turns or ratio of turns, the electrical valve have to be opened (Fig.7).

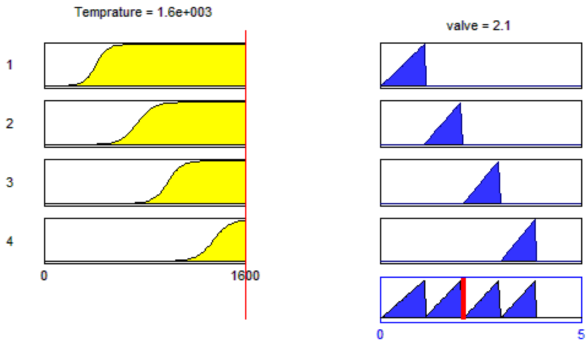

Figure. 7. Diagram of one of If-then fuzzy input-output rules via Matlab software

4-Conclusions

In this study we have presented an innovated method based on using fuzzy logic approach using infrared pyrometer sensor. We used four linguistic labels for the input (temperature) through sigma membership functions, four linguistic labels for output (amount of opening the valve) via triangular membership functions and four fuzzy rules for Fuzzy Interface System of the cooling control plant. The advantage of this method is that the sensor is a remote sense type and the system cools the grinding surface intelligently without needing to human operator via fuzzy rules. As a result, not only the cooling process needs less coolant due to the precise and simple operation of the fuzzy system base on fuzzy rules but also has higher speed,accuracy and efficiency.

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