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A user-friendly fuzzy-based system for the selection of electro discharge machining process parameters

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Abstract

This paper introduces a user-friendly intelligent system for the selection of electro discharge machining (EDM) parameters. In this system, a compact selection method based on expert rules, which were obtained from experimental results and extracted from the knowledge of skilled operators, is presented. Expert rules are evaluated by the fuzzy set theory. The developed fuzzy model uses fuzzy-expert rules, triangular membership functions for fuzzification and centroid area method for defuzzification processes. The system was developed on a PC using MATLAB Fuzzy Logic Toolbox. Inevitably, there are many machining parameters (discharge current, pulse duration, pulse interval, gap control, flushing rate, etc.) that should be considered in EDM processes. Selection of these parameters is still an ill-defined problem and generally relies on heuristics, which are not easy to model, and based on the experiences of specialists. In this system, discharge current, pulse duration and pulse interval are the inputs while the outputs are electrode wear, surface roughness and erosion rate. The remaining parameters are considered at constant rate during machining. The system is a compact and homemade tool that can be easily used by an average operator and provides the EDM parameters which lead to less electrode wear, better surface quality and more erosion rate according to the selected operation (finishing, roughing, etc.).

Keywords: Electro discharge machining; Fuzzy logic; Expert rules; User-friendly systems

1. Introduction

Electro discharge machining (EDM) is a thermal removal process extensively used for die manufacturing in industry. It is the most common process together with the CNC milling in the manufacture on plastic injection moulds. Mould-dies are usually machined on CNC machining centers. If CNC machining is not capable of generating certain geometries and accuracies then EDM is applied. It removes metal by discharging an electric current across a narrow dielectric filled gap between the tool and the workpiece. It uses heat to produce a tiny crater by melting and vaporization. Literally thousands of sparks per second are produced to erode the shape of the tool into the workpiece. EDM is applicable to all electrically conductive materials [1]. Additionally, EDM is widely used in two particular applications: shaping very tough metals such as the heat-resistant alloys of gas turbine blades, which cause severe tool-wear in conventional machining processes; and forming intricate shapes in press-tools and dies made of hard steel. The attainments of accurate and consistent EDM performance are mainly dependent on eight main factors [2]; polarity, open-circuit or no-load voltage, discharge current, pulse duration, electrode material, pulse interval, gap control and circulation rate. The first four of these are called planning parameters that are dependent on the type of machining operation and whether the cut is roughing or finishing operation. The last four are adjusted to give the best operating conditions for the machine used and the results required. The pulse interval, gap control and circulation rate are the operating parameters, which are automatically monitored and corrected in modern machines.

Which EDM parameters are important in machining stages and the relationships between them have been studied by researchers for many years. Cogun et al. [3] made a considerable number of experiments for investigating the wear of tool electrodes under different machining conditions in EDM die sinking. Haron et al. [4] recently determined possible correlation between the EDM parameter (discharge current) and machinability factors (material removal rate and electrode wear). In a similar vein, Lee and Li [5] studied the influence of operating parameters of

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EDM on the machining characteristics. Cogun and Akaslan [6], also investigated the variation of tool electrode wear and machining performance outputs, namely, the machining rate (workpiece removal rate), tool-wear rate and relative wear, with the varying machining parameters (pulse time, discharge current and dielectric flushing pressure) in EDM die sinking. In addition to these experimental works, some theoretical works have tried to form a relationship between EDM parameters. In the analytical view, Chen and Mahdivan [7] proposed a theoretical model estimating the material removal and surface quality of the workpiece. Similarly, Wang and Tsai [8] developed a semi-empirical model of the material removal rate on the workpiece and the tool.

With the increasing popularity of artificial intelligence (AI) tools in general, a considerable amount of research has been done in this area. Neural networks have been used for controlling and monitoring EDM processes [9–14]. Furthermore, fuzzy logic, another effective AI tool, is generally used for selecting, optimizing and controlling the process. Fuzzy logic is a mathematical approach of inaccurate reasoning that allows modeling of the reasoning process of humans in linguistic terms. For that reason, it is very suitable in defining the relationship between system inputs and desired outputs. It is also popular for its ability to develop expert rule-based systems. For that reason, a fuzzy system is the best way to implement human knowledge. Hashmi et al. [15] developed a model based on fuzzy logic for selecting cutting speed in single-point turning operations. In a similar vein, Arghavani et al. [16] applied a fuzzy logic approach to the selection of gaskets, for their sealing performance, based on system requirements. Lin et al. [17] applied the Taguchi method with fuzzy logic for optimizing the EDM process. Yilmaz et al. [18] used fuzzy logic for correlating the EDM parameters by using fuzzy sets (triangular shape) and expert rules for each machining stage.

Selection of EDM parameters is still an ill-defined problem and generally relies on heuristics, which is not easy to model, and is based on the experiences of specialists. Fuzzy set theory can be applied to processes like EDM in which the experiences of experts play important roles. Therefore, fuzzy logic actually imitates the performance of the specialist and provides decision-making capabilities in the presence of uncertainty. Knowledge and experiences of the skilled machine operators play an invaluable part in EDM (especially when only older and less sophisticated equipment is available). The objective of this work is to guide an end-user through the selection of EDM process machining parameters. For this purpose, experimental work was performed to develop the user-friendly intelligent EDM parameter-selection system using fuzzy logic. The developed system is a rule-based system and the rules were designed to process the EDM data.

2. Theoretical analysis of EDM parameters

In an EDM process, electrical circuits of several types produce the sparks with each of them having a different waveform of voltage and current of its own. Because these waveforms are the same or at least similar to each other and the energy of each spark can be calculated by following integration:

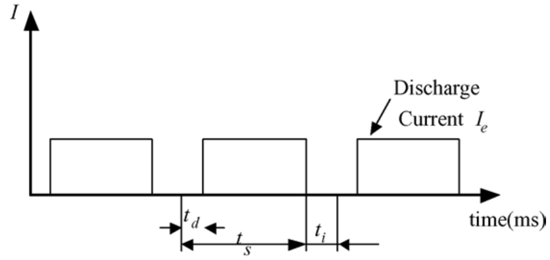

Fig. 1. The current–time diagram [7].

$$E_d = \int_0^{t_e} Q(t)\,dt \tag{1}$$

where t_e is the discharge duration time and $Q(t)$ the total power supplied for each discharge current. The value of $Q(t)$ can be computed from the discharge voltage (U_e) and current (I_e) as follows:

$$Q(t) = I_e(t)U_e(t) \tag{2}$$

Fig. 1 shows the current–time diagram. The time interval between switching the generator on and off is known as the pulse duration (t_s) while the time interval between switching the generator off and on for the next pulse is the pulse interval (t_i). The ignition delay time (t_d) is the period of time during which voltage remains at the value of the ignition voltage while the current stays at zero. The mean voltage value from ignition to power-off is the discharge voltage (U_e). The mean value of the current from ignition phase to power-off phase is the discharge current (I_e).

Substituting for $Q(t)$ from Eq. (2) into Eq. (1) results in the following equation:

$$E_d = \int_0^{t_e} I_e(t)U_e(t)\,dt \tag{3}$$

The pulse duration time, the ignition delay time and the discharge duration times have the following relationship:

$$t_s = t_e + t_d \tag{4}$$

where t_s is the pulse duration time. Neglecting t_d according to assumption, which is the ignition delay time, is constant and very short compared with the discharge time, gives:

$$t_s \approx t_e \tag{5}$$

Substituting for t_e from Eq. (5) in Eq. (3) results in:

$$E_d = \int_0^{t_s} I_e(t)U_e(t)\,dt \tag{6}$$

It is therefore clear that erosion rate is directly related to the energy of sparks. According to the thermophysical properties of electrode materials and an initially formed creator resulting from asymptotic temperature profile the following equation:

$$V_s = F_c \int_0^{t_s} I_e(t)U_e(t)\,dt \tag{7}$$