INTEGRATED CONTROL MECHANISM OF ELECTRICAL DISCHARGE MACHINING SYSTEM FOR HIGHER MATERIAL REMOVAL RATE

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This thesis is gratefully dedicated to my beloved family for their prayers and supports.

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ABSTRACT

A servo control system in Electrical Discharge Machining (EDM) system is a control system with an appropriate control algorithm to position electrode on a particular distance from workpiece during machining process. The gap between the electrode and the workpiece is in the range of 10 – 50 μm. This ideal gap is achieved by applying an appropriate control algorithm to the servo control system of the EDM, and maintaining this gap will improve the Material Removal Rate (MRR) during the machining process. A considerable number of unique methods were proposed in the control algorithm in order to bring the electrode to the optimum position. This research proposes a new method called Integrated Control Mechanism (ICM) to improve the MRR of the EDM system. A rotary encoder is used as an additional mechanical sensor for the feedback control system in order to limit the electrode movement. Modelling of EDM is further investigated to predict the MRR parameter and optimization of electrode control position. A Neural Network system is used to predict MRR where Particle Swarm Optimization (PSO) and Differential Evolution (DE) are studied and simulated to optimize the Proportional Integral Derivative (PID) control parameters for the EDM system. Research conducted shows that the proposed Feed Forward Artificial Neural Network improves the accuracy of prediction in determining MRR by 2.92% and PID parameter optimization is successfully applied either using PSO or DE. The ICM is successfully implemented and the result shows that MRR is higher when compared to the normal machining process.

ABSTRAK

Sistem kawalan servo dalam sistem Pemesinan Nyahcas Elektrik (EDM) adalah sistem kawalan dengan algoritma kawalan yang sesuai untuk meletakkan elektrod pada jarak tertentu dari bahan kerja semasa proses pemesinan. Jarak antara elektrod dan bahan kerja adalah dalam lingkungan 10 - 50 μm. Jarak ideal ini dicapai dengan menggunakan algoritma kawalan yang sesuai untuk sistem kawalan servo daripada EDM, dan dengan mengekalkan jarak ini akan meningkatkan Kadar Hakisan Bahan (MRR) semasa proses pemesinan. Sebilangan besar kaedah unik telah dicadangkan dalam algoritma kawalan untuk membawa elektrod ke kedudukan yang optimum. Kajian ini mencadangkan satu kaedah baru yang dikenali sebagai Mekanisme Kawalan Bersepadu (ICM) untuk meningkatkan MRR sistem EDM. Pengekod putar digunakan sebagai pengesan mekanikal tambahan bagi sistem kawalan maklum balas bagi menghadkan pergerakan elektrod. Pemodelan EDM seterusnya dikaji guna untuk meramalkan parameter MRR dan mengoptimumkan kedudukan kawalan elektrod. Sistem Rangkaian Neural digunakan untuk meramalkan MRR di mana Pengoptimuman Kerumunan Zarah (PSO) dan Evolusi Pembezaan (DE) dikaji dan disimulasi untuk mengoptimumkan parameter kawalan Kadar Kamir Pembeza (PID) untuk sistem EDM tersebut. Penyelidikan yang dijalankan menunjukkan bahawa Jaringan Saraf Buatan Suap Depan yang dicadangkan dapat meningkatkan ketepatan ramalan dalam menentukan MRR sebanyak 2.92% dan pengoptimuman parameter PID berjaya digunakan sama ada menggunakan PSO atau DE. ICM berjaya dilaksanakan dan keputusan menunjukkan bahawa MRR adalah lebih tinggi jika dibandingkan dengan proses pemesinan biasa.

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LIST OF SYMBOLS

α	-	Material properties factor
c_1, c_2	-	Inertia coefficients
d	-	Dimension variables optimization problems
$d(s)$	-	Actual position of electrode
$d_d(s)$	-	Disturbed distance
$d_e(s)$	-	Actual gap length
$d_m(s)$	-	Distance caused by metal removal
$e(s)$	-	Deviation between $r(s)$ and feedback signal $y(s)$
$f_r(s)$	-	Feed rate
F	-	Mutation scaling factor
G	-	Generation number
G_{best}	-	Best particle in the group
$H(s)$	-	Gap controller
I, I_{gap}	-	Current, Maximum discharge current
k_s	-	Magnification constant
K_d	-	Derivative gain
K_i	-	Integral gain
K_p	-	Proportional gain
n	-	Number of particle in the group
N	-	Nonlinear and time varying gain
ω_n	-	Natural frequency
ξ	-	Damping ratio
P_{best}	-	Particle with best value
r_1, r_2	-	Random value

$r(s)$	-	Reference
t, t_m	-	Time, machining time
t_D	-	Ignition delay time
T_{off}	-	Off time period
T_{on}	-	On time period
$U_{i,G}$	-	Trial vector in DE
v_i, v^{t+1}	-	Velocity of particle, new value of particle's velocity
V	-	Voltage
$V(s)$	-	Actual speed
V_g	-	Gap voltage
$V_{i,G}$	-	A donor vector in DE
V_s	-	Voltage reference
V_{sd}	-	Deviation between V_s and V_g
V_{spark}	-	Voltage level when the spark is occurred
w	-	Inertia weight
W_a	-	Weight of workpiece material after machining
W_b	-	Weight of workpiece material before machining
x_i, x^{t+1}	-	Particle, updated particle position
$X_{i,G}$	-	Vector as a candidate solution in DE
$y(s)$	-	Feedback signal

LIST OF ABBREVIATIONS

AC	-	Alternating Current
ANFFANN	-	A New Feed Forward Artificial Neural Network
ANN	-	Artificial Neural Network
CB	-	Circuit Breaker
CCW	-	Counter Clock Wise
CNC	-	Computer Numerical Control
CPU	-	Central Processing Unit
CW	-	Clock Wise
DC	-	Direct Current
DE	-	Differential Evolution
DSP	-	Digital Signal Processor
EDG	-	Electrical Discharge Grinding
EDM	-	Electrical Discharge Machining
EWR	-	Electrode Wear Rate
EWW	-	Electrode Wear Weight
FFANN	-	Feed Forward Artificial Neural Network
GA	-	Genetic Algorithm
HMP	-	Hybrid Machining Process
IAE	-	Integral Absolute Error
ICS	-	Integrated Control System
ISM	-	Integrated Servo Mechanic
LCD	-	Liquid Crystal Display
MRR	-	Material Removal Rate
P	-	Proportional

PD	-	Proportional Derivative
PI	-	Proportional Integral
PID	-	Proportional Integral Derivative
PMEDM	-	Powder Mixed Electric Discharge Machining
PPG	-	Pulse Power Generator
PSO	-	Particle Swarm Optimization
PWM	-	Pulse Width Modulation
QEI	-	Quadrature Encoder Interface
RC	-	Resistor Capacitor
RISC	-	Reduced Instruction Set Computer
SR	-	Surface Roughness
TWR	-	Tool Wear Rate
WRW	-	Workpiece Removal Weight

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Along with the rapid growth in the industrial machining processes, Electrical Discharge Machining (EDM) has gained widespread recognition as a spark erosion machine which can provide important practical and economic advantages in many fields, notably in production engineering and tool making. An EDM system is a significant machining technique used for finishing parts, for example, in an automotive industry, aerospace and other commercial components [1]. This technique allows for processing high strength alloys and ceramics polycrystalline diamond ultra-hard conductive material because the machining process is not directly affected by the substance of the workpiece. Ceramic (ultra-hard conductive material) also can be machined using this method. In addition, with the use of hard material in Biomedical Engineering, the EDM process contributes greatly to this field.

The machining performance indicator of EDM machines, which includes Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (SR) are important values in order to enhance the capability of the EDM machine. Many studies have been carried out in order to discuss and discover a suitable approach to improve the performance of EDM machines. Efforts have also been made to enhance the performance of the power generator, controller to adjust the position of the electrode gap, materials which are suitable for use as an electrode and workpiece, the flushing system, engineered dielectric materials, and vibrating electrodes. Researchers have also studied methods of implementing the multi-spark in EDM to increase the MRR [2-5]. Furthermore, several studies have reported various simulations and models for MRR prediction [6-9]. Among the three parameters above, the most dominant is MRR, since MRR directly affects the production cost even though the value of MRR is not the only indicator that measures the performance of EDM machines. Higher MRR means the faster the machining process, that will save time and production cost. The value of MRR is strongly influenced by the performance of the control system to position the electrode towards the workpiece during the machining process. Therefore, using a control mechanism in order to increase the MRR is very challenging. In the EDM process, electrical parameters such as current, frequency, and duration of injected pulse (T_{on} and T_{off}) influence the MRR, while mechanical movement of the electrode position also has a significant effect on machining output, MRR. Estimating electrical parameters to predict MRR is possible by modelling, however, the available models from previous studies need to be improved. On the other hand, the challenge in research is to maintain the distance of the electrode towards the workpiece, therefore a shorter machining time could be achieved with better MRR.

1.2 Problem Statement

Material removal rate (MRR) is an important parameter in determining the performance of an Electrical Discharge Machining (EDM) System. MRR is determined by the ability of the controller to position the electrode to the workpiece or, in other word, to regulate the gap between the electrode and the workpiece. Currently controllers rely on the feedback voltage as an input to the controller that has a stochastic process in nature, so sometimes the position of the electrode will be too far away from the workpiece. This situation causes the ignition delay time becoming too large and eventually resulted in missing spark, thus reducing the MRR. To overcome this problem, an additional feedback sensor is proposed that monitors the electrode movement mechanically which is not affected by the stochastic nature of the gap voltage. When the electrode is moving upwards and too far away from the workpiece, the retraction movement will be forced to stop as to maintain the gap. By maintaining a suitable gap, an appropriate delay time is achieved while machining take place.

1.3 Objectives

Based on the current issue of EDM, there is a demand to research designing EDM's servo control system. The expected outcome of this work would be to maintain the electrode position towards the workpiece that increases the material removal rate during the machining process. During the research work, several objectives are listed as follows:

(i) To develop an EDM model to predict MRR using Artificial Neural Network (ANN).

(ii) To optimize the PID (Proportional Integral and Derivative) controller by application of Particle Swarm Optimization (PSO) and Differential Evolution (DE)

(iii) To improve Material Removal Rate (MRR) by applying additional mechanical sensor to control the electrode movement within the acceptable limit.

1.4 Scope of Research

Scope of research for this study is outlined as follows:

(i) A critical literature review of the effort to improve MRR by considering several EDM systems. In this regard, fundamental theory, control mechanism and EDM performance are reviewed.

(ii) An attempt to predict the MRR by considering related parameters is carried out by developing a model based on the Artificial Neural Network. The related parameters become an input to the model and MRR is the output. In this modelling process, experimental data are obtained from past research to train and investigate the capability of the MRR prediction.

(iii) An optimization process to achieve optimum PID parameters is carried out by PSO and DE algorithms. Several PID controller formations, i.e., P, PD, PI and PID are optimized using Integral Absolute Error as an objective function.

(iv) The implementation of ICM is applied to the laboratory scaled EDM machine. The limitation is activated when the electrode retraction is too wide. This forces the gap to be around 10 – 50 microns. During the experimental work Copper is used as the electrode, whereas Brass and Steel are used as the workpieces. MRR and ignition delay time are measured for comparison and analysis.

(v) Experimentation of machining process for Copper-electrode and Brass or Steel-workpiece in order to measure MRR and ignition delay time.

1.5 Significance of Study

Higher MRR is the key performance of the EDM process in order to accomplish faster machining. The study of MRR is important as it directly affects the duration of the time processes and consecutively influences the cost of production. Moreover, the study to predict MRR is significant in estimating the time of the EDM process based and based on the experimentation parameters, the ANN is expected to accurately predict the MRR

The value of MRR is essential to the selection of suitable control systems for positioning the electrode accordingly. Therefore the study of the acceptable distance between the electrode and the workpiece is necessary. An incremental rotary encoder as a sensor to limit the electrode movement is proposed as part of the Integrated Control Mechanism (ICM) to keep retraction in an effective range. The application of Particle Swarm Optimization (PSO) and Differential Evolution (DE) in order to gain maximum optimization of PID is crucial to ensure the best performance of PID as a controller to govern the DC motor.

1.6 Summary of Methodology

During this research work, some activities are arranged in order to reach the main objective of this research and generally the flow is described as shown in Figure 1.1.

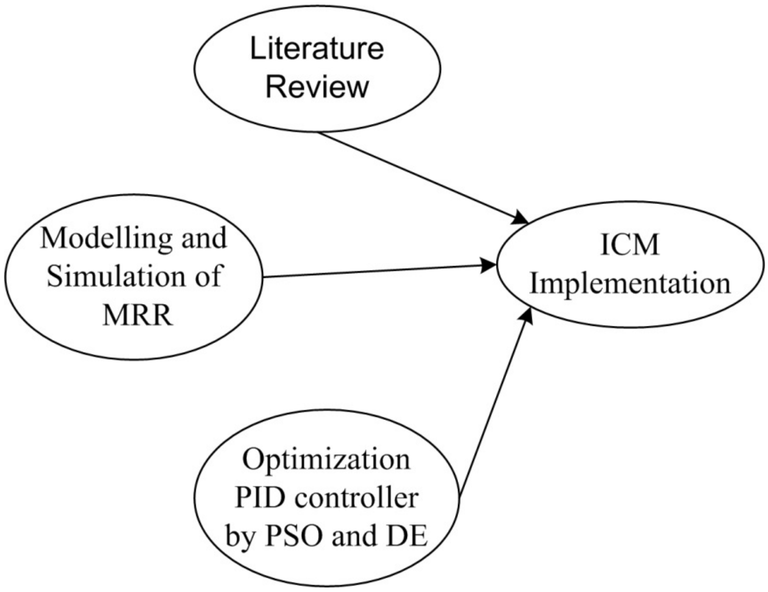

Figure 1.1 Flow of research work.

Generally, this research work is conducted through modelling, simulation and implementation. The following methodology will be implemented in order to accomplish the objectives of this research:

(i) Literature review of EDM systems

A study of previous EDM work, especially servo mechanics used for controlling electrode positions is reviewed. Their strong points and limitations based on several evaluating factors are emphasized. In addition, finding a gap in this field becomes the main concern of this review, particularly on the issue of controlling electrodes during machining in EDM systems.

(ii) Modelling and predicting MRR of EDM system using the Artificial Neural Network.

In order to achieve a deep understanding of EDM systems, designing a proper and accurate model of the EDM control system is essential. A simulation is conducted to determine a suitable model which affects the machining performance. The Artificial Neural Network (ANN) is used to model the EDM system, especially in terms of the determination of MRR.

(iii) Optimization of PID controller gain using Particle Swarm Optimization PSO) and Differential Evolution (DE) Algorithms.

Once a functional EDM model is developed, it can be used to simulate the EDM control system which describes the dynamic of the EDM process. The PID controller, which is used in this control system, will be tuned in order to get an optimum result. Particle Swarm Optimization and Differential Evolution algorithms are applied and compared. This optimization process will provide a reference when implementing the integrated servo mechanics methods throughout this research.

(iv) Integrated Control Mechanism of the EDM system

An Integrated Control Mechanism (ICM) of the EDM system will be implemented to improve the machine's capability. Its performance is evaluated through comparing machining results between the existing control system and the proposed method. The proposed technique uses an incremental rotary encoder as an additional sensor to control the electrode movement within the acceptable limit. The effectiveness of this proposed controller is validated through some experiments conducted using Copper electrode and Brass and/or Steel workpieces.

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