Integrated Control of Electrical Discharge Machining (EDM) using PSoC

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Abstract. Electrical discharge machining (EDM) is one of the earliest non-conventional machining in order to manufacture very accurate 3-D complex components on any electrically conductive materials. In die-sinking EDM, a pulse discharge occurs in a small spark gap between electrically conductive workpiece and electrode in dielectric medium. This paper proposed a new integrated control system using Programmable System-on-Chip (PSoC) for Die-sinking EDM in order to enhance Material Removal Rate (MRR). The MRR result of EDM-PSoC system is higher than EDM-Ben Fleming system due to the effect off high speed processing data analysis using PID algorithm in PSoC microcontroller and leads to improving system efficiency 41%.

1. Introduction

Electrical Discharge Machining (EDM) is one of non-conventional machining material removal process and also known as a non-contact process based on thermoelectric energy between a workpiece and an electrode [1-4]. Based on the thermal erosion principal, EDM also is most popular in making high precision and complex shaped parts on any electrically conductive materials such as hardened steel, carbides and ceramic materials [5,6]. Furthermore, EDM has become one of the most broadly used in manufacturing technologies, which is in mold-making tool, die industries, making prototype and production parts [7,8]. There are three types of EDM that used for different applications such as die-sinking EDM [9,10], wire-cut EDM [9,11,12] and grinding EDM [13]. In general, EDM system consists of several basic elements which are power supply, spark generator or pulse generator, servo system, mechanical structure and dielectric fluid [9,14] as shown in Figure 1.
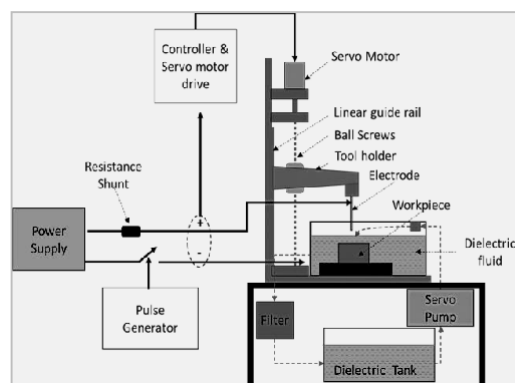

Figure 1 EDM system block diagram.

Moreover, EDM is one of electro-thermal non-traditional type material removal technique which is a series of repeated electrical discharges between the electrode and workpiece in presence of a dielectric fluid [4]. When the electrode is moved towards the workpiece until the gap is small enough, then the electric field become strongest and the voltage become sufficiently high [15]. The dielectric fluid in the sparking gap breaks down into ionized particles and an ionization channel is started. In the meantime, when the voltage at the sparking gap exceeds the voltage gap, the circuit is opened and drastically reduces the temperature at the sparking gap, triggering a collapse of the vapor bubble and generates a high-energy spark temperature with the pressure [16, 17]. Then, the sudden thermal energy is produced that causes melting and vaporization of the workpiece which creates small crater. The eroded particles (debris) are removed from the electrode and workpiece surface with the erosive effect by flushing process [18].

According to the literatures [19, 20], the history of EDM begins in 1770, when English Chemist, Dr Joseph Priestly as a main founder of the EDM process revealed the continuous erosive results that obtained from the sparks series. Afterwards, during Second World War, Dr Boris Lazarenko and Dr Natalya Lazarenko in Moscow were assigned by Soviet Government to solve a wear problem caused by sparking between tungsten electrical contacts, which was particularly critical problem for maintenance of automotive engine. Then, they put the electrodes in mineral oil and found the sparks were more uniform. Both the scientists had an idea to use the controlled sparking as an erosion method and then first EDM machines (as known as Spark Erosion) were developed during the war. The Lazarenko EDM system with power supply controlled by resistance-capacitance (RC) circuit which was widely used in 1950 [11]. In 1960, the modification of EDM was done by combination of pulse and solid-state generators that reduced the previous problems with weak electrode as well as the inventions of orbiting system. Then, in 1970, the less number of electrodes in EDM was developed in order to create the cavities. Finally, a computer numerical controlled (CNC) EDM was invented in United State (1980) [21]. Since now, the EDM system has widely used to machine many conductive materials such as composite, carbide, ceramics and others [22].

2. Literature survey

There is numerous study of Die-sinking EDM design technique in improving and performance measures. Regarding to researcher, Yahya [23] has studied the optimization of copper and graphite electrode to measure MRR performances in die-sinking EDM system onto steel workpiece using eZdsp controller. Whereas, Zhang [24] have investigated the processing efficiency and quality have been improved in micro-EDM using interval type-2 fuzzy logic based two stage servo feed controller. Then, Andromeda [25, 26] has discussed the optimization of Proportional Integral Derivative (PID) to define gain parameter in servo actuator system using Particle Swarm Optimization and Differential Evolution algorithm. In addition, Pawade and Banwait [27] have explained that only 3% of researchers focus on automation of EDM process and then suggested a new Programmable logic controller (PLC) based flexible controller for die sinking EDM in order to achieve high level automation and to reduce the operator dependency. Jesudas and Arunachalam [28] have developed spark gap controller for a tabletop micro EDM setup using AT89C51 microcontroller. After that, Yadav [29] have described the controlled melting and vaporization of excess material from difficult to machine, electrically conductive material with stringent design requirements using thermal energy generated by spark between two electrodes completely dipped in dielectric and applying a pulsating voltage between them. Thampi [30] proposed a cost effective automatic spark gap adjustment system for a tabletop micro EDM experimental setup using Arduino microcontroller. Then, Tseng [31] have developed an automated EDM system with real-time monitoring to obtain real-time status retrieval and display of crucial parameters on a screen using VisSim software, Arduino microcontroller and PID controller.

3. Experimental Work

The two mild steel S24C samples which have density, $\rho = 7.85$ mg/mm^3 were selected as workpiece in this experiment. Fifteen experimental runs were carried out individually using EDM-Ben Fleming

system and EDM-PSoC system at 4 Ampere (A) of current setting, respectively. Besides that, there have some parameters were considered in this experiment as tabulated in Table 1.

Table 1. Parameter setup for experimental of EDM system.

Parameter used	Value set
V_{gap}	15 V – 20 V
V_{oc}	100 V
T_{off}	30 µs
T_{on}	60 µs
Frequency	11.11Khz

In this experiment, the current consumption considered as constant. Prior to the running experiment, the weight of both workpiece were taken before and after machining using electronic balance (Shimadzu ATX224). Then, the workpiece with dimensions $(30 \times 10 \times 10)$ mm^3 was placed on the adjustable mini jaw bench clamp. Pure tungsten in cylindrical form with diameter 1mm was used as electrode. The type of dielectric medium used in this experiment is Vitalube EDM 99 SD. After machining process, the workpiece was dried using air dryer to remove dielectric medium on the surface in order to obtain accurate results. The MRR values for both systems were calculated using Equation 1 [28] and tabulated in Table 2.

$$MRR = (Wi-Wf)/(T)(\rho) \tag{1}$$

Where Wi and Wf represent the workpiece weight before and after machining process. Then, ρ indicates the workpiece density whereas T is machining time that measured in minutes.

3.1. EDM-Ben Fleming System.
The pulse generator has been controlled using 555 timers integrated circuit (IC) where T_{on} and T_{off} was set up using potentiometer in EDM-Ben Fleming system. When the duration was turned ON, Hexfets were be ON position to allow the current flows in order to create discharge process. In the meantime, during machining process, the Hexfets was OFF position when the interval was turn OFF. After that, the voltage feedback was send the signal to comparator circuit. When the voltage feedback value was higher than the reference value, it was generated a drive signal to the drive servo mechanism in order to decrease the gap between the electrode tool and the workpiece, and then vice versa.

3.2. Proposed Integrated Control System (EDM-PSoC System).
The Programmable System-on-Chip (PSoC) microcontroller have been used in order to control the whole system of die sinking of EDM design system including pulse generator, servo motor, flushing and timer. There have some advantages of a single PSoC device such as it capable to integrate almost 100 digital and analog peripheral functions, minimize board space, reducing design time, low power consumption and system cost while improving system efficiency as reported by other researchers [29-31]. In PSoC microcontroller, there have consists of a CPU core, configurable analog and the digital blocks which is a several chips combination of performing function together. This EDM-PSoC system divided in two parts which is mechanical and electrical. In mechanical part consists of the EDM structure, pump, filter, tank, tool and workpiece whereas in electrical part contains of DC power supply unit (SMPS type), PSoC microcontroller, servo motor, Input-output board (IO) and input button. Besides that, the power supply unit and EDM structure of the existing die sinking EDM was operated as an input to PSoC microcontroller in this system.

The EDM-PSoC system process was started from inserted input data in parameter setting (time, pulse for T_{on} and T_{off} and voltage gap) were set up through button and viewed on a LCD display. Then, PSoC was send the data signal through IO card in order to control the tool position, pulse time (T_{on} and T_{off}), power supply output and flushing speed as per earlier setting. The voltage and current gap from die sinking system worked as data feedback in PSoC microcontroller to control the gap between electrode and workpiece using proportional integral derivative controller (PID) algorithm. This EDM-

PSoC process was repeated until the time was finished. The schematic diagram of EDM-PSoC system was illustrated in Figure 2.
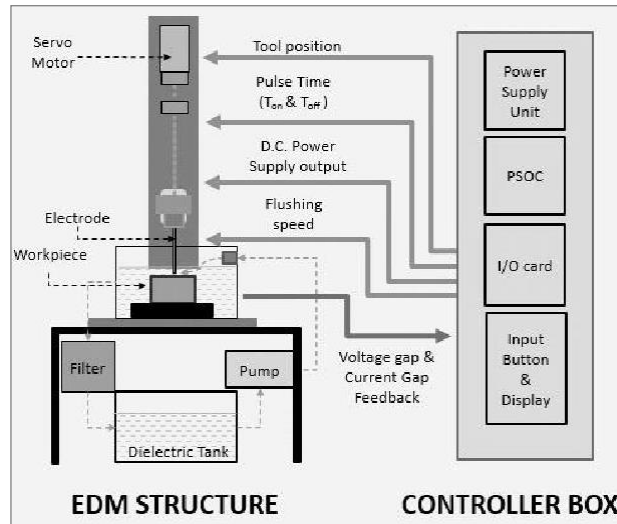

Figure 2 EDM-PSoC system schematic diagram.

4. Results and Discussions

In this experiment, both EDM-Ben Fleming system and EDM-PSoC system have been carried out with fifteen runs on two different workpieces. Table 2 indicates the comparison of MRR values for both systems. The highest value of MRR using EDM-Ben Fleming is 0.0460 mm^3/min, whereas EDM-PSoC system is 0.0616 mm^3/min. Besides that, the lowest MRR value for EDM-Ben Fleming system is 0.0312 mm^3/min and EDM-PSoC system was 0.0497 mm^3/min.

Table 2. The MRR values result for EDM-Ben Fleming system and EDM-PSoC system at 4 Ampere of current setting.

	EDM-Ben Fleming			**EDM-PSoC**		
Runs	*Weight Before (mg)*	*Weight After (mg)*	*MRR (2A) (mm3/min)*	*Weight Before (mg)*	*Weight After (mg)*	*MRR (2A) (mm3/min)*
1	22.0702	22.0666	0.0460	23.3020	23.2976	0.0557
2	22.0666	22.0600	0.0420	23.2976	23.2896	0.0514
3	22.0600	22.0509	0.0386	23.2896	23.2758	0.0582
4	22.0509	22.0392	0.0373	23.2758	23.2597	0.0514
5	22.0392	22.0236	0.0398	23.2597	23.2362	0.0599
6	22.0236	22.0201	0.0446	23.2362	23.2315	0.0596
7	22.0201	22.0142	0.0376	23.2315	23.2223	0.0586
8	22.0142	22.0053	0.0378	23.2223	23.2091	0.0563
9	22.0053	21.9914	0.0443	23.2091	23.1906	0.0587
10	21.9914	21.9754	0.0408	23.1906	23.1711	0.0497
11	21.9754	21.9722	0.0408	23.1711	23.1668	0.0554
12	21.9722	21.9673	0.0312	23.1668	23.1584	0.0532
13	21.9673	21.9582	0.0386	23.1584	23.1439	0.0616
14	21.9582	21.9470	0.0357	23.1439	23.1262	0.0565
15	21.9470	21.9304	0.0423	23.1262	23.1051	0.0538
	Means x̄		0.0398	Means x̄		0.0560
	Standard Deviation(*s*)		0.0038	Standard Deviation(*s*)		0.0035

A comparison graph of MRR values for fifteen runs between EDM-Ben Fleming system and EDM-PSoC system at 4 Ampere as shown in Figure 3. According to the graph, the MRR values are increase

horizontally and shows the MRR stability for both systems. In addition, the MRR value is higher when using EDM-PSoC system (red color) as compared with EDM-Ben Fleming system (black color) as shown in Figure 3. It can explained based on the rate of discharge energy, as high concentration of discharge energy in the spark gap leads to rapid melting and metal vaporization, which is leads to rises of MRR [32].
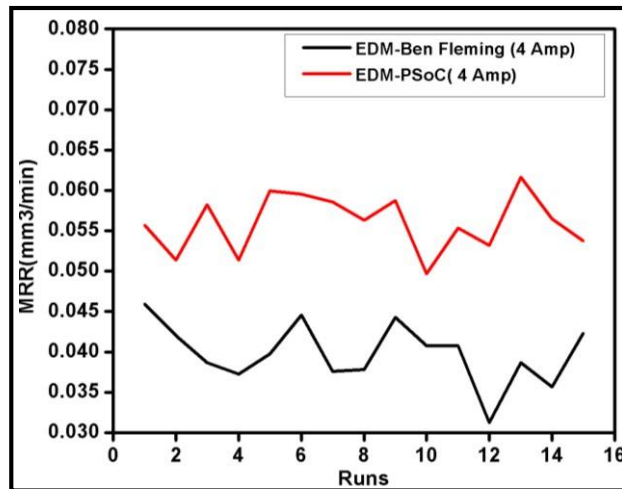

Figure 3 Comparison of MRR for EDM-Ben Fleming system and EDM-PSoC system at 4 Ampere.

Based on Table 2 and Figure 4, the mean ($\bar{x}$) of MRR values of fifteen runs using EDM-Ben Fleming system is 0.0398 mm^3/min. Whereas, the mean ($\bar{x}$) of MRR value of fifteen runs by EDM-PSoC system is 0.0560 mm^3/min. The standard deviation value from the mean of MRR for EDM-PSoC system (0.0035) shows lowest as compared with EDM-Ben Fleming system (0.0038). Based on the analysis, the EDM-PSoC system indicates have higher consistency of MRR compared with EDM-Ben Fleming system due to its standard deviation value nearest to the mean data [35].
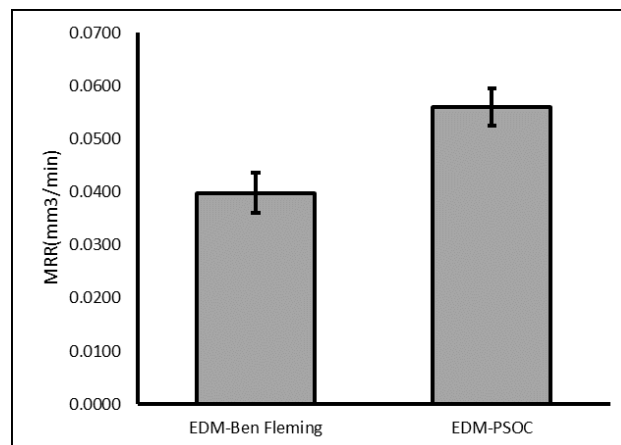

Figure 4 Mean ($\bar{x}$) of MRR for both systems with their respectively standard deviation.

5. Conclusion
In this study, the performance of EDM has been analyzed based on Material Removal Rate (MRR) via EDM-Ben Fleming system and EDM-PSoC system. The effect of high speed processing data analysis using PID algorithm in PSoC microcontroller shows higher in MRR as compared by EDM-Ben Fleming system and leads to improving system efficiency to 41%. The higher MRR consistency by EDM-PSoC system proves that the machining condition more stable as it able to remove the material nearly consistent for each run on the workpiece.

6. Acknowledgement

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