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Original Research Article

Performance analysis of iso current pulse generator on machining characteristics in EDM process

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ABSTRACT

Extremely hard materials can be easily machined by Electrical Discharge Machining process due to its thermal erosion nature. In this process, the amount of material removed is directly proportional to the discharge current. Due to the stochastic nature of the thermal erosion process, the discharge current is varied for every applied electrical pulse. It results in different levels of material removal over the material surface during machining process. The volume of the crater is determined by the discharging energy. The variation in the discharging energy produces high surface roughness, which is influenced by discharge current. A constant duration discharge current is needed throughout the process to produce better surface quality. In this research, an iso duration current pulse generator has been proposed to achieve good surface finish. An experimental performance evaluation has been conducted with conventional transistor pulse train generator and modified iso current pulse generator by Taguchi L_{27} orthogonal array design. The machining characteristics have been evaluated for both the pulse generators. It is found the that modified iso duration current pulse generator has produced better surface quality with higher material removal rate than the conventional transistor pulse train generator.

1. Introduction

1.1. Thermal erosion process

Electrical Discharge Machining (EDM) otherwise known as thermal erosion process is one of the non-conventional manufacturing processes, where tool and workpiece does not come in contact with each other during the machining process. This process can produce a crater in any conducting material by thermal energy irrespective of the hardness of the material. Since the EDM process does not involve direct contact between the workpiece and tool such as that of any conventional manufacturing process, there are no vibration problems in such a process. This causes less tool wear compared to the conventional manufacturing processes. In this process, the two conductors i.e. tool and workpiece are separated by an isolating medium. Based on alignment of tool and workpiece, this process can be classified as die sinking and

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wire cutting EDM processes. In die sinker machining, the tool shape is a replica of required profile. In Electrical Discharge Machining, a controlled DC pulse (30–100 V) is applied between the tool and the workpiece separated by small air gap (0.01–0.5 mm) with high frequency (100 kHz–10 MHz). The air gap is filled by a dielectric medium. When the dielectric medium reaches its breakdown voltage, the ionization column is formed between the workpiece and the tool electrode. It leads to the generation of a higher thermal energy in terms of 8000 °C to 12000 °C. Because of the higher thermal energy, the material is melted and vaporized. The melted material in the air gap can be removed by the flushing process. Fig. 1 explains the schematic diagram of a basic Electrical Discharge Machining setup. For improving surface quality in thermal erosion process, many researchers have implemented new techniques with it. Abbas et al. [1] discussed about new trends involved in Electrical Discharge Machining.

1.2. Need for the research

Ho and Newman [2] reviewed about research areas involved in the thermal erosion process. It has been reported that very few researches have been done related to the electrical parameters involved in this process. Normally the EDM process utilizes two types of the pulse generators: RC relaxation pulse generator and transistor pulse train generator. Since there is a time lag for charging the capacitor for each cycle of supply, RC relaxation pulse generator can produce low frequency DC pulse only. Due to its low frequency operation, it removes only less amount of material. The high frequency transistor pulse train generator can produce high material removal rate. Han et al. [3] explained about the merits of transistor pulse train generator over RC relaxation pulse generator. Due to the stochastic nature, the EDM process is not having a constant duration discharge current throughout the process. Han et al. [4] discussed about the nature of electrical discharging process and need for iso duration pulse generator. Jahan et al. [5] narrated the demerits of transistor pulse train generator over RC relaxation pulse generator. They concluded that surface finish by RC relaxation generator is better than that of transistor pulse train generator. Due to its higher frequency operating region, transistor pulse train generator can remove more material than RC relaxation generator. But it does not produce good quality surface. This drawback of transistor pulse train generator can be overcome by iso duration current pulse generator. Kuppan et al. [6] found that peak current determines the machining characteristics in EDM process. Tsai et al. [7] concluded that peak current and pulse duration mainly decide the machining characteristics in the EDM process.

Mohan et al. [8,9] proved that the peak current decides the crater volume on the surface. The surface finish depends on the crater volume. The crater volume is determined by the amount of energy delivered per pulse. Muthuramalingam and Mohan [10,11] explained about the influence of iso duration pulse and tool electrode properties in the EDM process. If the duration of the discharge current during machining is constant, the crater volume stays the same. It can produce a good quality surface. Nowicki et al. [12] discussed about the surface finish modification of workpiece using the EDM process. From the literatures, it is found that only few literatures are available in area of altering the pulse shape to enhance the surface quality. In the present study, a modified iso discharge current pulse generator has been proposed and developed for improving the machining characteristics of the EDM process.

2. Pulse generator circuit in thermal erosion process

2.1. Conventional transistor pulse train generator

Fig. 2 shows schematic arrangement of transistor pulse train generator. Since the conventional RC relaxation pulse generator gives low material removal rate, the transistor pulse train generator is mostly employed.

The transistor pulse train generator utilizes a high frequency response semi conductor device for the switching operation. Due to its high frequency operation, this pulse generator can produce higher material removal rate. The main drawback of this pulse generator is its ability to produce the random energy discharges. Owing to this ability to produce the random discharge energy levels, the transistor pulse generator

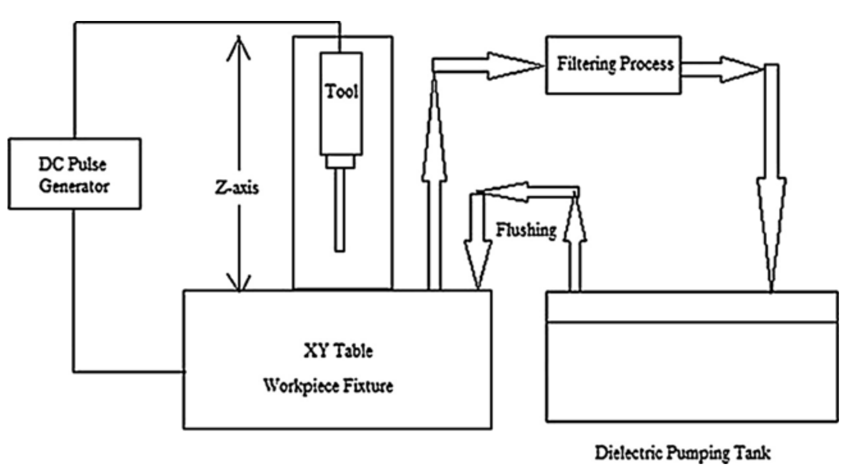

Fig. 1 – Schematic diagram of basic Electrical Discharging Machining setup.

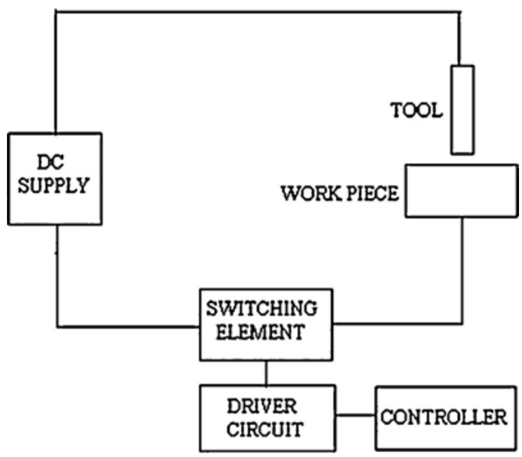

Fig. 2 – Schematic diagram of transistor pulse train generator.

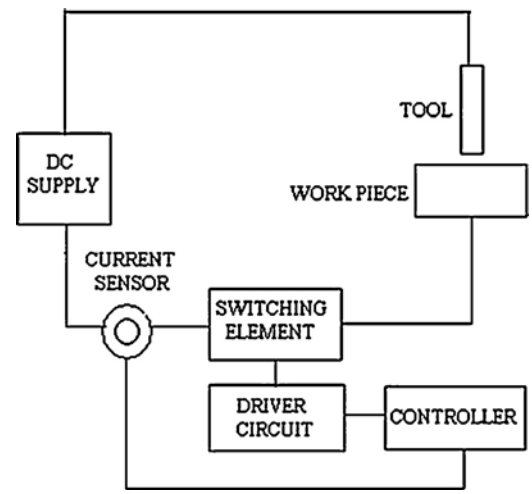

Fig. 3 – Schematic diagram of iso current pulse generator.

produces poor surface finish. The semi conductor device can be controlled by a controller circuit. Due to its non-linear nature, conventional transistor pulse train generator can produce a different duration of the discharge current for each cycle of supply.

2.2. *Modified iso duration current pulse generator*

It is important to modify the transistor pulse train generator for producing good surface quality. Salonitis et al. [13] derived the equation for heat input to the EDM process as shown in Eq. (1), which realizes that peak current and spark duration have the dominant role to produce higher temperature for machining.

$$r_s = 2040 I^{0.43} t_s{}^{0.44} \quad (1)$$

where r_s is the heat source radius in μm, I is the peak current in A and t_s is spark duration in μs. The main drawback of pulse train generator is the random energy distribution over the surface.

It can be overcome by the iso duration current pulse generator. The circuit has been modified by adopting a current sensing unit. Fig. 3 shows the schematic arrangement of modified iso duration current pulse generator. The zero crossing edges have been easily sensed by the current sensing unit. The duration between upward zero crossing edge and downward zero crossing edge has been designed to be constant throughout the process. The modified iso current pulse generator has liberated equal discharge energy over the surface to obtain better surface finish. This generator has also been designed to produce larger crater volume during roughing level of the process and to deliver low discharge energy during the finishing level of the process.

3. Experimental design

In the present section, the selection of process input parameters, response parameters, and process variables have been described.

3.1. *Selection of input and response parameters*

Since the discharge energy (E) in die-sinking Electrical Discharge Machining is mainly influenced by electrical process parameters such as gap voltage (V), discharge current (I) and duty factor (D) as per the following Eq. (2), these parameters have been selected as the input parameters.

$$E = VID \quad (2)$$

Material removal rate (MRR) and surface roughness (R_a) have been selected as response parameters in this study. Experiments have been designed and conducted by Taguchi design of experiments. Since all three input parameters have interactions between them, L_{27} orthogonal array was selected for conducting experiments.

3.2. *Measurement of response parameters*

Since the production time is influenced by the material removal rate (MRR), it has been taken as one of the response parameters. The material removal rate has been computed based on the difference between the volumes of the workpiece before and after machining and it has been represented in mm^3/min. The weight of the workpiece has been measured based on the following Eq. (3) with the help of Uni-Blog high precision 0.1 mg resolution digital balance.

$$MRR = \frac{(W_b - W_a)1000}{\rho_w T} \quad (3)$$

W_b is the weight of the workpiece before the machining process (g); W_a is the weight of the workpiece after the machining process (g); ρ_w is the density of the workpiece (g/cm^3) and T is the machining time (min).

The surface quality of EDM product can be well evaluated by the surface roughness [11]. The value of surface roughness (R_a) has been calculated by SE1200 kasaka lab surfcorder surface roughness tester. The cutoff length has been taken as 0.8 mm with the evaluation length of 2.4 mm as per ISO97R standard for the machining process. The surface roughness tester has calculated the surface roughness (R_a) by the

Table 1 – Selection of process variables for Electrical Discharge Machining.

Process variables	Description
Pulse generator type	Transistor pulse train, iso current pulse
Work piece	AISI 202 stainless steel
Tool	Copper
Dielectric medium	Total EDM3 oil
Flushing	Normally submerged
Depth of cut (mm)	2
Gap voltage (V)	40,60,70
Peak current (A)	9,12,15
Duty factor	0.4,0.6,0.8

following Eq. (3) for center line average roughness. The surface roughness can be computed based on this method as per the following Eq. (4).

$$R_a = \frac{1}{n}\int_0^L |y|dx \tag{4}$$

where l is the cutoff length, n is the number of deviations in the cutoff length and y is the height of peak or valley.

3.3. *Selection of process variables*

Since AISI 202 stainless steel has been utilized in the production of railway structural components, it has been selected as the work piece material whereas the copper tool electrode has been used for tool electrode material with the diameter of 4 mm. The selection of the process variables for Electrical Discharge Machining is shown in Table 1.

4. Results and discussion

This section discusses about the effects of conventional transistor pulse train generator and modified iso duration current pulse generator on machining characteristics of the thermal erosion process. The response parameters such as material removal rate and surface roughness by different pulse generators with various process variables have been compared and analyzed. It has been realized that the duration of the discharging current has been different for every spark. The discharge current with constant duration for every spark has been obtained by iso duration current pulse generator.

4.1. *Effect of pulse generators on surface roughness*

The surface roughness of the workpiece in thermal erosion process is determined by the size of crater volume and discharge energy distribution over the surface. Salonitis et al. [13] derived the equation for crater volume and surface roughness in terms of discharge current as Eqs. (5)–(7).

$$V_c = 0.5\Pi S {r_c}^2 \tag{5}$$

$$r_c = A(It_s)^B \tag{6}$$

$$R_a = 0.25(((r_c + r_s)/r_c)^2)S \tag{7}$$

where V_c is crater volume in mm^3, S is crater depth in μm, I is the discharging current in A, t_s is machining time in μs, A and B are constants which depend on the workpiece material, r_c is the crater radius in μm. The non-linear nature of transistor pulse train generator has caused larger crater volume with difference in size over the surface and also created the higher surface roughness. It is found that transistor pulse generator has produced random discharging energy. This drawback has been avoided in machining process with iso current pulse generator by producing equal and less discharge energy distribution over the surface during the finishing level of the process. The schematic distribution of discharging energy on the surface by transistor pulse train generator and iso current pulse generator is shown in Fig. 4. The effect of pulse generators on the surface roughness has been illustrated in Fig. 5.

While analyzing the value of surface roughness with the different combinations of process variables level, it is found that the surface roughness with iso current pulse generator is lower than that of the transistor pulse train generator. The crater volume is affected by discharging energy. It can be varied by the duration of the discharge current. The random energy distribution on the surface has been caused by the variations in the energy per spark. So conventional transistor pulse generator would not be able to produce good surface finish. In iso current pulse generator, equal discharge energy per spark has been obtained by producing a constant duration of discharging current throughout the machining process. This has caused uniform thermal energy distribution on the machining surface and thus has produced the better surface finish.

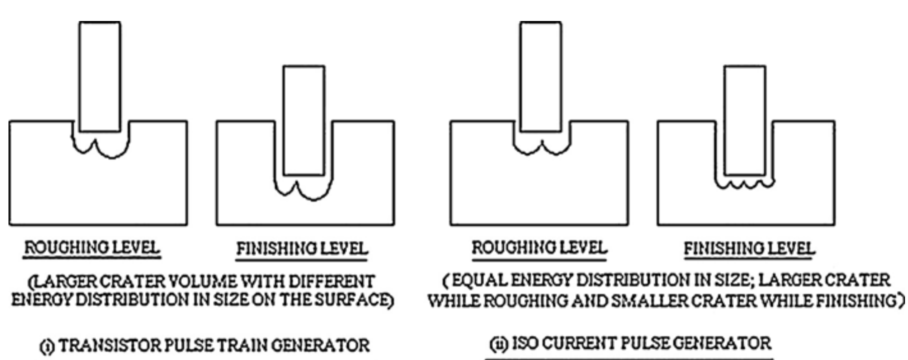

Fig. 4 – Energy distribution on the surface with different pulse generators.

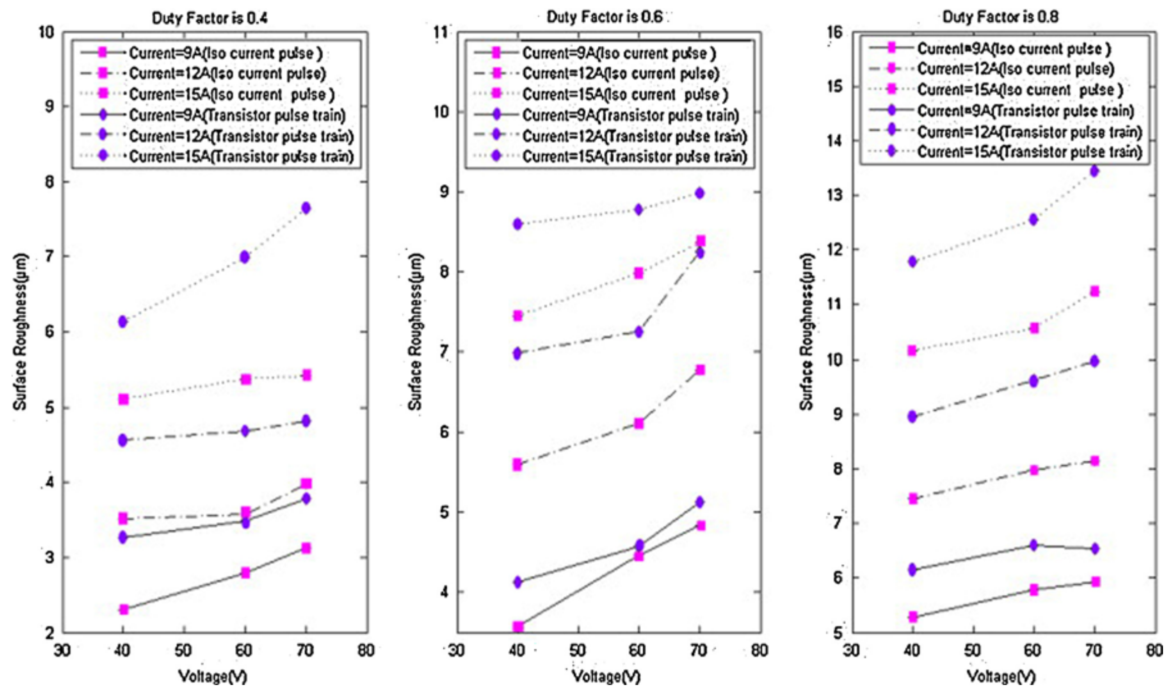

Fig. 5 – Effect of pulse generators on surface roughness.

4.2. *Effect of pulse generators on material removal rate*

The efficacy of pulse generator is mainly determined by the surface finish and the material removal rate. Salonitis et al. [13] also derived the equation for material removal rate in terms of crater volume as Eq. (13).

$$\mathrm{MRR} = (V_c N)/t_m \tag{8}$$

where MRR is the material removal rate in mm^3/min, V_c is crater volume in mm^3, N is the number of pulses, and t_m is the machining time in minutes. Owing to its nature of producing larger craters in the roughing level and tiny craters in the finishing level of the machining process, the modified iso current pulse generator has produced the higher material erosion rate in such a process. Due to this switching sequence operation, iso current pulse generator has produced high

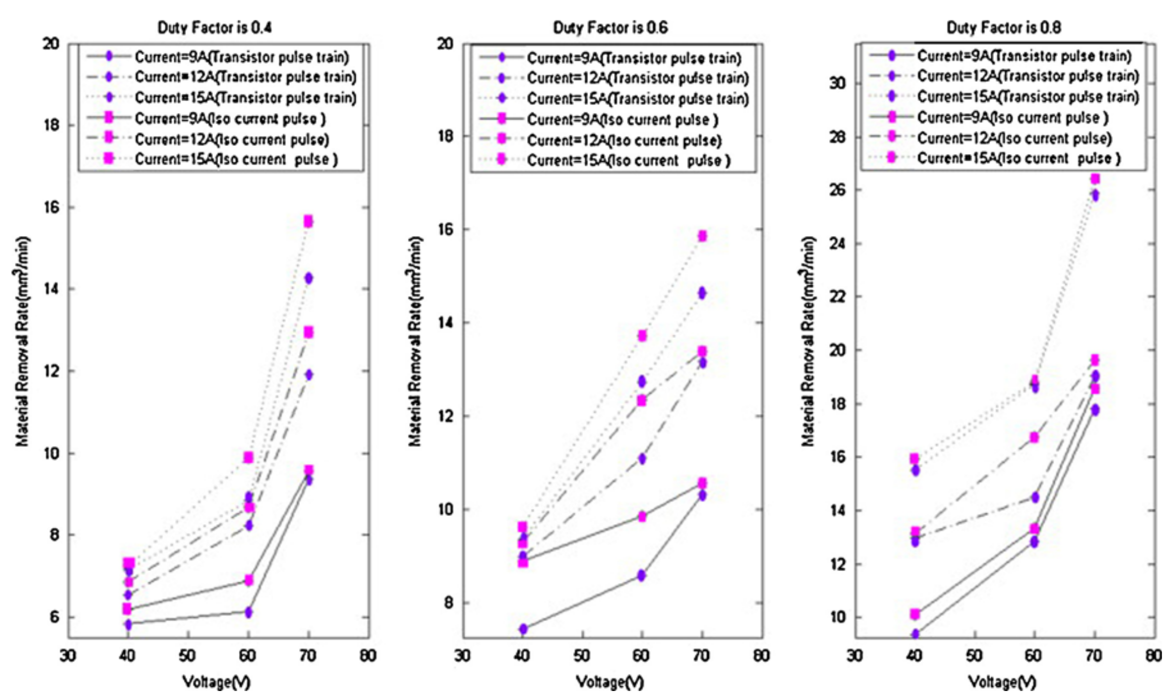

Fig. 6 – Effect of pulse generators on material removal rate.

material removal rate with better surface finish. Fig. 6 shows the effects of pulse generators on the material removal rate in thermal erosion process. It illustrates that iso duration current pulse generator has produced higher material removal rate.

4.3. *Surface topography analysis of machined surface*

The surface topography images of the machined surfaces have been acquired using the SIPCON vision measuring systems. Fig. 7 shows the various surface topography images of machined surfaces in EDM process by transistor pulse train generator and iso current pulse generator. Larger size craters with unequal discharge energy distribution over the surface could be found in the machining process with transistor pulse train generator. The modified iso current pulse generator has produced smaller size craters with equal discharge energy distribution over the surface. From Fig. 7, it is proved that iso current pulse generator has produced better surface finish than transistor pulse train generator.

4.4. *Effects of input parameters on surface finish with Taguchi method*

Main effect plot shows how each input factor affects the response characteristics in any process. It is presented when a different level of a factor dominates the response differently. When the response line is parallel to the x-axis, then there is no main effect present. Each level of the factor affects the characteristic in the same way and the characteristic average is the same across all factor levels. When the response line is not parallel to the x-axis, then there is a main effect present. Different levels of the factor affect the characteristic differently. In the present study, the main effect plots have been achieved with the help of Minitab software package. Figs. 8 and 9 show the main effects of input parameters on surface finish. Based on the Taguchi design of experiments, a smaller, better level signal to noise ratio has been selected for surface roughness. The deviation from the x-axis denotes influence of input factors on the response. From Figs. 8 and 9, it is proved

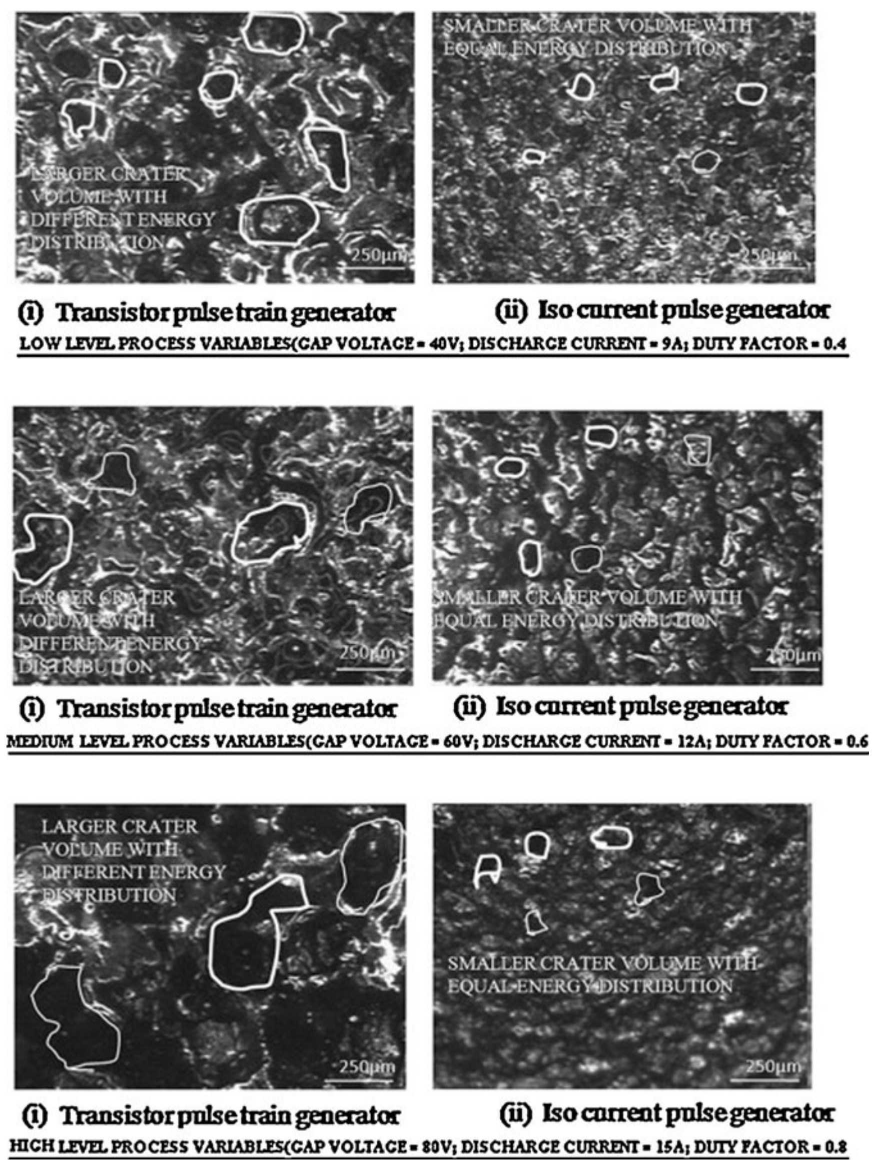

Fig. 7 – Surface topography analysis of machined surface with different process variables in EDM process.

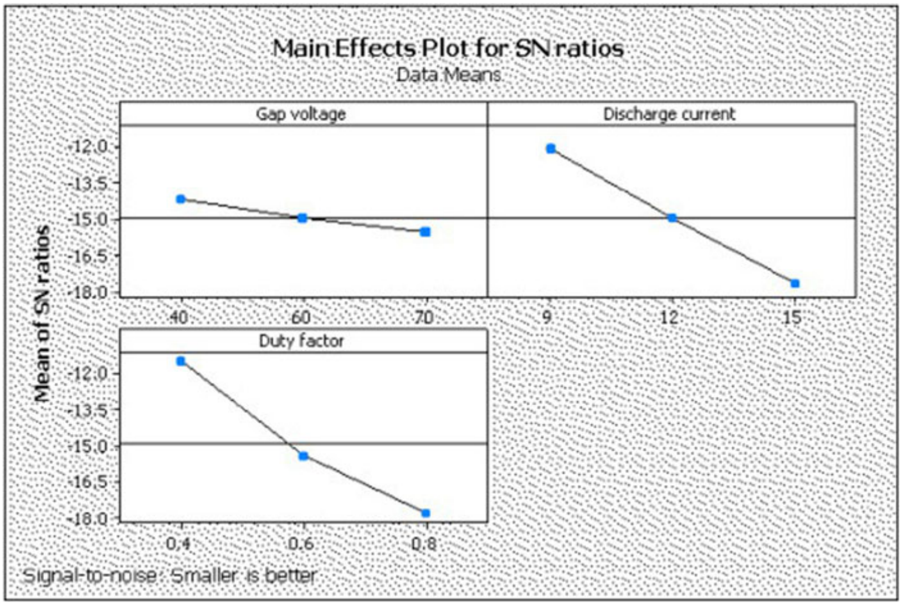

Fig. 8 – Main effects plot for SN ratios with surface roughness.

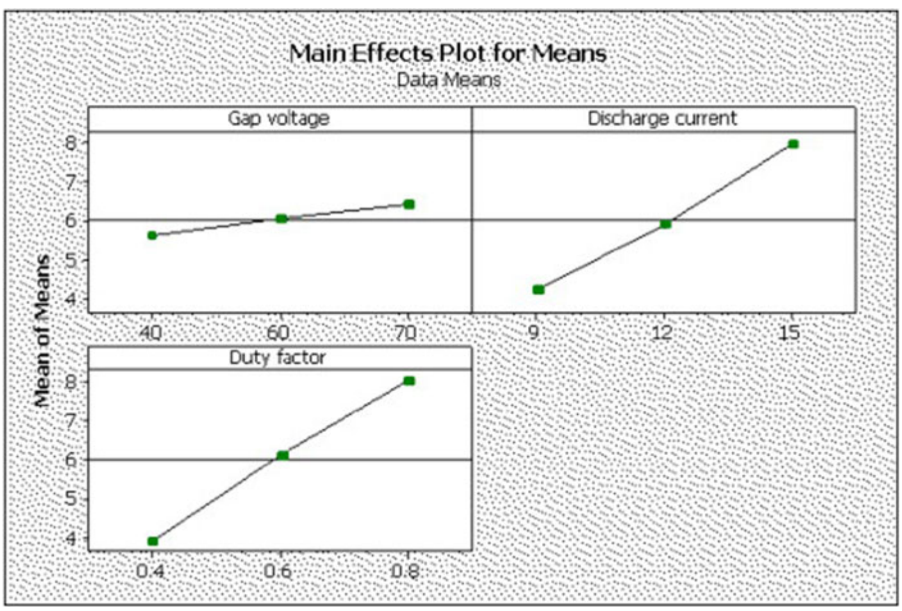

Fig. 9 – Main effects plot for means with surface roughness.

that discharge current and pulse duration in terms of duty factor have a significant contribution on the surface finish. Iso current pulse generator has controlled these parameters and it has given better surface finish than conventional pulse generator.

5. Conclusion

With the view of obtaining better surface finish in the Electrical Discharge Machining process, a detailed experimental investigation has been conducted by transistor pulse train generator and iso duration current pulse generator. In addition, a comparative discussion has been done on process parameters influencing the response parameters of the process. Based on the experimental results the following conclusions have been made:

(i) The iso duration current pulse generator can produce better surface quality in EDM process.
(ii) The iso duration current pulse generator can produce a higher material removal rate compared to the transistor pulse train generator.
(iii) Discharge current and duty factor have the most influence on determining machining characteristics in Electrical Discharge Machining.

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