OPEN ACCESS
ISSN: 2249-6645

International
Journal
Of Modern Engineering Research (IJMER)

Effect of Process Parameters on Surface Roughness In EDM Process

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ABSTRACT: *Electrical discharge machining (EDM) is a non-conventional process of machining. It is the most important machining process in tool engineering. General advantages over other machining processes are accuracy, surface quality and the fact that hardness and stiffness of a work piece material is not important for the material removal. The EDM has become mature technology but the researches and improvements of the process are still going on. The main reason why EDM is used, that there still does not exist a machining process, which could successfully replace this.*

The results of an experimental investigation carried out on CNC EDM CREATOR CR-6C, to study the effects of machining out on parameters i.e., pulsed current, pulse On Time and Off Time on material removal rate and surface roughness of STAINLESS STEEL (SS-410). The work material is machined with COPPER electrode by varying the pulsed current at straight polarity. Investigations indicate that the material removal rate and surface roughness increases with the increase in pulsed current.

Keywords: *EDM, Kurtosis, Pulsed current, skew ness, Surface roughness.*

I. INTRODUCTION

Manufacturing processes can be broadly divided into two groups and they are Primary manufacturing processes and secondary manufacturing process. The former ones provide basic shape and size to the material as per designers to name a few. Secondary manufacturing processes provide the final shape and size with tighter control on dimensional, surface characteristics etc. Material removal processes are mainly the secondary manufacturing processes.

Electro Discharge Machining (EDM) is an electro-thermal non-traditional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark.

EDM is mainly used to machine difficult –to- machine materials and high strength temperature resistant alloys. Work material to be machined by EDM has to be electrically conductive.

1.1.Process parameters:

The process parameters in EDM are mainly related to the waveform characteristics.

The waveform is characterized by the

- The open circuit voltage – V_0
- The working voltage - V_w
- The maximum current - I_o
- The pulse on time – the duration for which the voltage pulse is applied - T_{on}
- The pulse off time - T_{off}
- The gap between the work piece and the tool – spark gap – δ
- The polarity – straight – polarity – tool (-ve)
- The dielectric medium
- External flushing through the spark gap.

II. SURFACE ROUGHNESS

Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface.

Roughness plays an important role in determining how a real object will

Interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces roughness is often a good predictor of the performance of mechanical components, since irregularities in the surface may sites for cracks or corrosion.

Although roughness is usually undesirable, it is difficult and expensive to control in manufacturing. Decreasing the roughness of a surface will usually increase exponentially its manufacturing costs.

2.1. Measurement:

Roughness may be measured using contact or non-contact methods. Contact methods involve dragging a measurement stylus across the surface, these instruments include profilometers. Non-contact methods include interferometry, confocal microscopy, electrical capacitance and electron microscopy.

For 2D measurements, the probe usually traces along a straight line on a flat surface or in a circular arc around a cylinder surface. The length of the path that it traces is called the measurement length. The wavelength of the lowest frequency filter that will be used to analyze the data is usually defined as the sampling length. Most standards recommend that the measurement length should be at least seven times longer than the sampling length, and according to the Nyquist - Shannon sampling theorem it should be at least ten times longer than the wavelength of interesting features. The assessment length or evaluation length is the length of data will be used for analysis. Commonly one sampling length is discarded from each end of the measurement length.

For 3D measurements, the probe is commanded to scan over a 2D area on the surface. The spacing between data points may not be the same in both directions.

In some cases, the physics of the measuring instrument may have a large effect on the data. This is especially true when measuring very smooth surfaces. For contact measurements, most obvious problem is that the stylus may scratch the measured surfaces. Another problem is that the stylus may be too blunt to reach the bottom of deep valleys and it may round the tips of sharp peaks. In this case probe is a physical filter that limits the accuracy of the instrument.

There are also limitations for non-contact instruments. For example instruments that. Rely on optical interference cannot resolve features that are less than some fraction of. The frequency of their operating wave length. This limitation can make it difficult to accurately measure roughness even on common objects, since the interesting features May be well below the wavelength of light. The wavelength of red light is 400nm, while the Ra of a ground shaft might be 2000nm.

2.2. Analysis:

The first step of roughness analysis is often to filter the raw measurement data.To remove very high frequency data since it can often be attributed to vibrations or Debris on the part surface. Next, the data is separated in to roughness, waviness and form. This can be accomplished using references lines, envelope methods, and digital filters, fractals or other techniques. Finally the data is summarized using one or more of the roughness parameters, or a graph.

2.3. Roughness parameters:

Each of the roughness parameters is calculated using a formula for describing the Surface. There are many different roughness parameters in use, but Ra is by far the most common. Other common parameters include R_z, R_q and R_a. Some parameters are used only in certain industries or within certain countries. For example, the Rk family of parameters is used primarily within France.

Since these parameters reduce all of the information in a profile to a single number, great care must be taken in applying and interpreting them. Small changes In how the raw profile data is filtered , how the mean line is calculated, and the Physics of the measurement can greatly affect the calculated parameters.

By convention every 2D roughness parameters is a capital R followed by additional characters in the subscript. The subscript identifies the formula that was used, and the R means that the formula was applied to a 2D roughness profile. Different capital letters imply that the formula was applied to a different profile. For example, R_a is the arithmetic average of the roughness profile, Pa is the arithmetic average of the unfiltered raw profile, and SA is the arithmetic average of the 3D roughness.

Each of the formulas listed in the tables assumes that the roughness profile has been filtered from the raw profile data and the mean line has been calculated. the roughness profile contains n ordered, equally spaced points along the trace, and Yi is the vertical distance from the mean line to the data point. Height is to be positive in the direction, away from the bulk material.

2.4. Amplitude parameters:

Amplitude parameters characterize the surface based on the vertical deviation of the roughness profile from the mean line. Many of them are closely related to the parameters found in statistics for characterizing population samples. For example, Ra is the arithmetic average of the absolute values and RT is the range of the collected roughness data points.

The amplitude parameters are by far the most surface roughness parameters found in the United States on Mechanical Engineering drawings and in technical literature. Part of the reason for their popularity is that they are straight forward to calculate using a digital computer.

III. EXPERIMENTAL PLAN

3.1 Methodology:

Straight polarity is employed in which, tool material is connected to negative terminal and the work piece to the positive terminal. In each case one parameter only is varied, and the rest are maintained Constant. The surface roughness was observed varying the process Parameters of EDM.

Rustic oil is used as a dielectric fluid in which both the tool material and work piece are immersed.

3.2 Method of Roughness Measurement:

The Taly surf is an electronic working on carrier modulating Principle. This instrument gives the information more rapidly and accurately. This instrument records the static displacement of the stylus and is dynamic instrument like profilometer.

The measuring head of this instrument consist of a diamond stylus of about 0.002mm tip radius and skid or shoe which is drawn across the Surface by means of a motorized driving unit (gear box), which provides three motorized speeds giving respectively *20 and *100 horizontal magnification and a speed suitable for average reading.

A neutral position in which the pick up can be traversed manually is also provide in which the pick up can be arm the stylus forms an armature Which pivots about the center piece of E-shaped stamping as shown in fig. on two legs of (outer pole pieces) the E-shaped stamping there are coils carrying an A.C. current.

These two coils with other two resistances from an oscillator. As the armature is provided about the central leg, any movement of the stylus causes the air gap to carry and thus the amplitude of the original A. current flowing in the coils is modulated. The output of the bridge is thus consists of modulation only as shown in figure. This is further demodulated so that the current now is directly proportional to the vertical displacement of the stylus only.

Fig 3.1 Surface roughness tester

The demodulated output is caused to operate a pen recorder to produce a permanent record and a meter to give a numerical assessment directly. The marking medium is an electric discharge through a specially treated paper which blackens at the point of the stylus, so this has no distortion due to drag and record strictly rectilinear one.

3.3 Skew ness:

It is the third statistical moment, which defines the asymmetric spread of the height distribution of the surface profile. A surface having normal height distribution will have zero skewness. A negative skewed surface is predominantly valley biased while the positively skewed surface is predominantly peak biased, mathematically, skewness (R_a) is given by:

$$R_{sk} = \frac{1}{nR_q^3}\sum_{i=1}^{n} y_i^3$$

Where,

R^2 = variance

$y_i = (z_i - \bar{z})$

Z_I = ordinate of the profile

$\bar{Z}$ = mean if ordinate of profile

I = lag numbers = 1, 2, 3……N

N = total number of ordinates.

A profile having negative skewness is said to be valley biased where as profile having positive skewness is said to be peak biased.

3.4 Kurtosis:

It is the forth statistical movement which defines the height of peaks of the profiles. A dataset with normal distribution will have a kurtosis of 3. A surface profile having a kurtosis is $R_k>3$ is said to be leptokurtic and a profile having $R_k<3$ is called platikurtic. Mathematically, kurtosis is given by

$$R_{ku} = \frac{1}{nR_q^4}\sum_{i=1}^{n} y_i^4$$

3.5 Equipment:

Fig 3.2 CNC CREATOR CR-6C

EDM machine has the following machine major modules Dielectric reservoir, pump & circulation system

- Power generator and control unit
- Working tank with work holding device
- X-y table accommodating the working table
- The tool holder
- The servo system to feed the tool

3.6 Work material (SS-410):

Grade 410 is the basic martensitic steel: like most non-stainless steels it can be hardened by a "quench-and-temper" heat treatment. It contains a minimum of 11.5 per cent chromium, just sufficient to give corrosion resistance properties. It achieves maximum corrosion resistance when it has been hardened and tempered and then polished. Grade 410 is a general purpose grade often supplied in the hardened, but still machinable condition resistance is required.

Martensitic stainless steels are optimized for high hardness, and other properties are to some degree compromised. Fabrication must be by methods that allow for poor weldability and usually the need for a final heat treatment. Corrosion resistance of the martensitic grades is lower than that of the common austenitic grades and their useful operating temperature range is limited by their loss of ductility at sub-zero temperatures and loss of strength by over-tempering at elevated temperatures.

3.6.1 Composition:

Typical compositional ranges for grade 410 stainless steels are given by in table 4.1

Table 4.1 composition ranges for 410 grade stainless steel

Grade	C	Mn	Si	P	S	Cr	Mo	Ni	N
410 min	-	-	-	-	-	11.5	-	0.75	
410 max	0.15	1.00	1.00	0.040	0.030	13.5	-	-	-

3.6.2. Mechanical Properties**:**

Typical mechanical properties for grade 410 stainless steels are given in table 4.2

Table 4.2 mechanical properties of 410 grade stainless steel

Tempering Temperature (°c)	Tensile Strength (MP_a)	Yield Strength 0.2% Proof(MP_a)	Elongation (%in50mm)	Hardness Brinell (HB)	Impact Charpy V(J)
Annealed	**480 min**	**275 min**	**16 min**	-	-
204	1310	1000	16	388	30
316	1240	960	14	325	36
427	1405	950	16	401	-
538	985	730	16	321	-
593	870	675	20	255	39
650	755	575	23	225	80

3.6.3 Physical properties:

Typical physical properties for annealed grade 410 stainless steel are given in table 4.3

Table 4.3 physical properties of 410 grade stainless steel in the Annealed condition.

Grade	Density (kg/m³)	Elastic Modulus (GP_a)	Mean coefficient Of thermal expansion (um/m/ºC)	Thermal Conductivity (W/m.k)	Specific heat o-100c (j/kg.k)	Electrical resistivity (nΩ.m)
410	7750	200	9.9 11.4 24.9	28.7	460	570

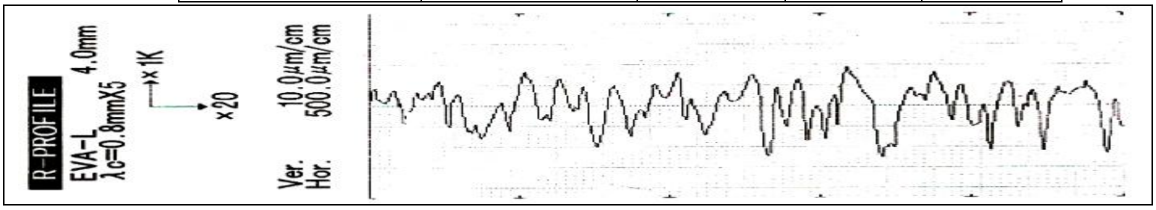
IV. RESULTS AND ANALYSIS

4.1 Effect of pulse current:

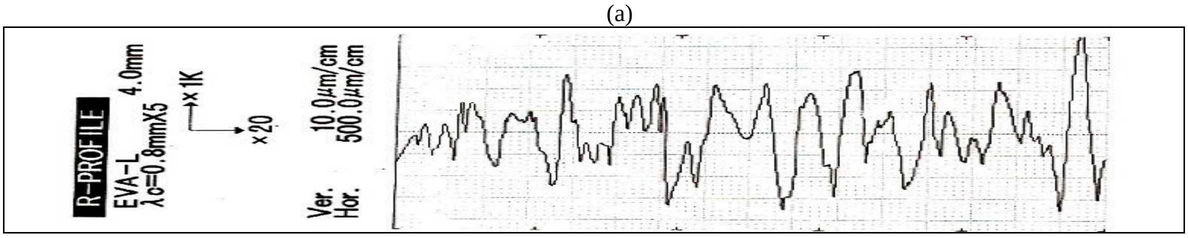
The surface roughness profiles of specimen for differing values of pulse current are illustrated in fig 5.1.The center line average roughness (R_a), Skewness (R_{sk}), Kurtosis (R_{ku}) and Material removal rate (MRR) in respect of differing values of pulse current are given in table 4.1.

Table 4.1: **CLA roughness, Skewness, Kurtosis & MRR for differing pulse current**

PULSE CURRENT (I) Amps	CLA Roughness R_a (μm)	Skewness R_{sk}(μm)	Kurtosis R_{ku}(μm)	M.R.R (mg/min)
3.0	1.80	-0.25	2.51	1.3949
5.0	2.67	-0.36	2.62	4.0700
7.0	2.93	-0.44	2.95	6.6405
9.0	5.75	-0.11	2.73	7.3772
11.0	5.83	-0.06	2.59	7.2978



(a)



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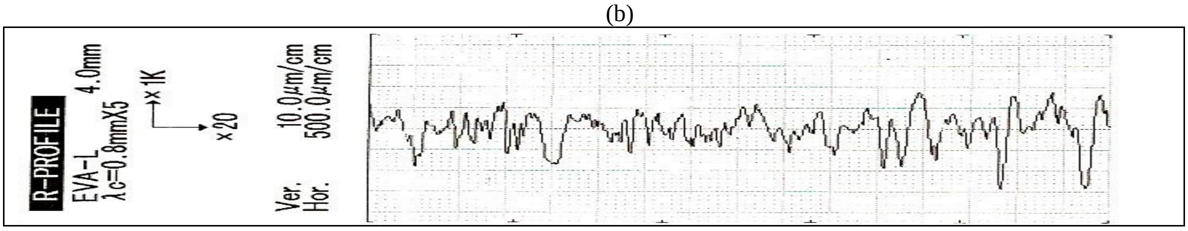


(c)

Fig 4.1 Surface profiles of specimen for differing pulse currents (a)3.0 Amps (a) 5.0 Amps (c) 7.0 Amps

The variation of CLA roughness R_a with the increase in pulse current is shown in Fig.4.2.

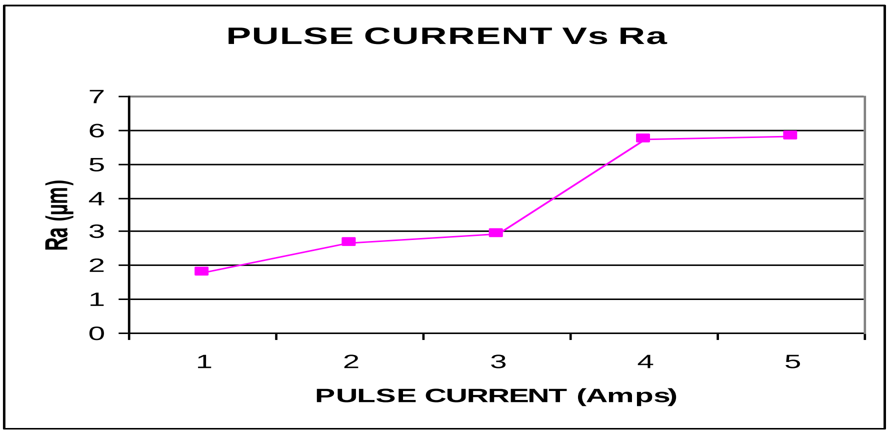


Fig. 4.2 variation of CLA roughness R_a with the increase in pulse current

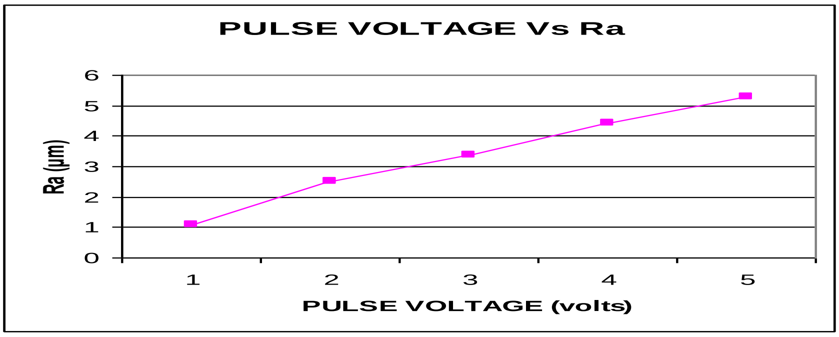


Fig 4.3 Variation of CLA roughness with pulse voltage

From the fig 4.2 and Fig.4.3, It is observed that with the increase in pulse current the CLA roughness .

(R_a) also increases for every input pulse current. We are aware that the energy content in the spark in EDM is given by the following relation, $E_s = VIT_{on}$ Where, V= pulse voltage, I= pulse current,T_{on} = pulse time on

From the above relation, it can be seen that the pulse energy increases as the pulse current increases. Higher energy content of the pulse is naturally associated with high heat content which is capable of removing higher work material. Thus, the craters formed due to the removal of work material are deeper for higher levels of pulse currents. Such deeper craters formed in series due to the movement of tool form a surface structure of higher roughness at higher pulse currents. Thus the surface roughness increases as the pulse current increases.

The variation of skew ness with that of pulse current is illustrated in **Fig 4.4.**

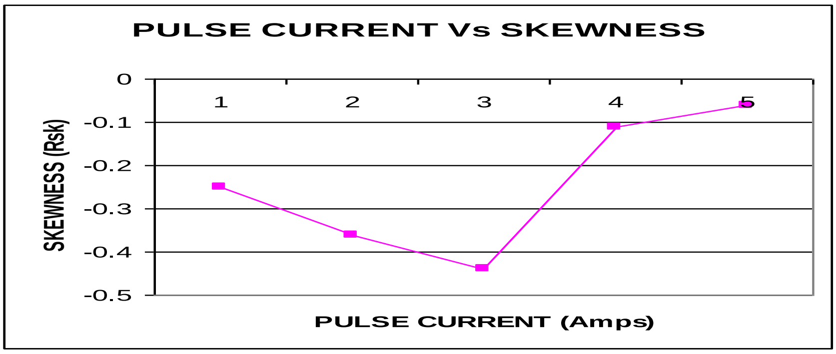


Fig 4.4. Variation of skewness with pulse current

From Fig 5.3. It is observed that with the increase in pulse current, the skewness decreases up to certain point and then increases with increase in pulse current (as we can observe at point 3). As pulse current increases then the energy of spark raises up which results in increase in metal removal rate, thus form craters on the work specimen, which are deeper. Thus deeper craters naturally result in valley biased surface structure i.e., negative skew ness. Thus increase in pulse current result in surface whose skewness decreases with pulse current. However, as the pulse current increases beyond certain limit, the material removal mechanism by high energy content pulses undergoes some modification from the one at lower pulse current. At higher pulse currents, the energy content in the pulse is more. Such high energy content pulses allow for side sparks besides the regular frontal sparks from the face of the tool. Such side sparks naturally remove the work material which widens the craters rather than forming deeper craters. Such wide craters result in surface structure whose skewness increases. Thus, the skewness increases as the pulse current increases beyond some limit.
The variation of kurtosis with that of pulse current is illustrated in **Fig 4.5**

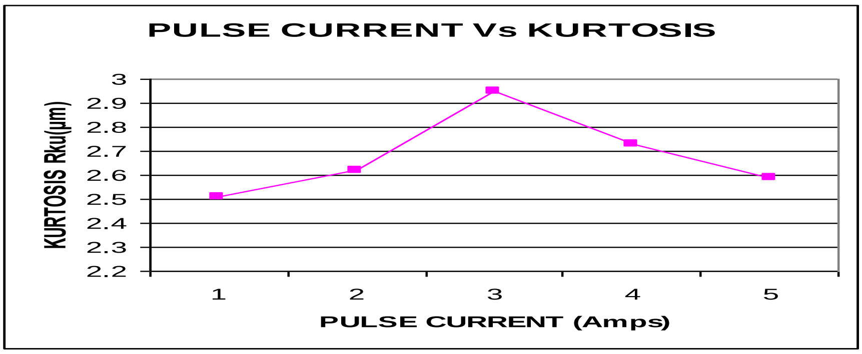


Fig 4.5. Variation of kurtosis with pulse current

From the fig 5.5, It is observed that with the increase in pulse current the variation of kurtosis increases up to certain point and then decreases with increase in pulse current (as we can observe at point 3). Such different behavior of kurtosis as pulse current increases can be explained in the similar lines as was the case with variation of skew ness with pulse current. The increase in pulse current increases the energy content which in turn removes higher work material with craters whose peaked-ness is more. Thus the kurtosis increases as the pulse current increases. However as the pulse current increases beyond certain limit, the side sparks come into existence which naturally alter the shape of the craters formed on the work surface. Thus, the kurtosis decreases as the pulse current increases beyond certain limit. The variation of Material removal rate with that of pulse current is illustrated in **Fig 4.6.**

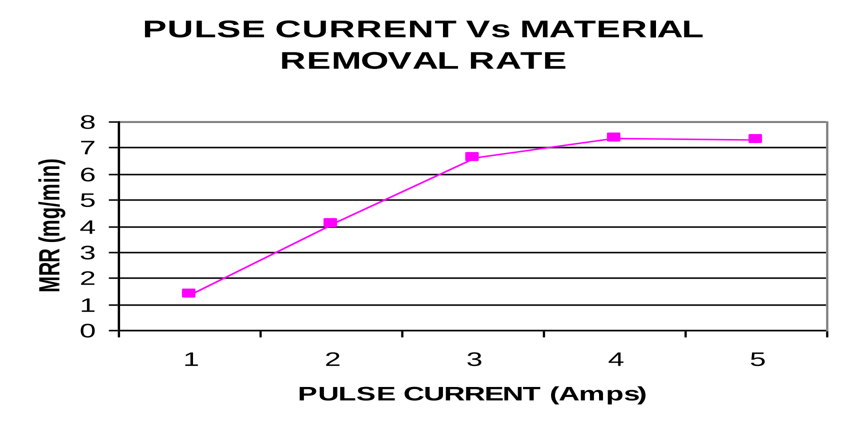


Fig. 4.6. Variation of material removal rate with the pulse current.

From the fig 4.6, It is observed that with the increase in pulse current the Material removal rate increases with increase in pulse current. It is understood from the previous discussion that the pulse energy increases as the pulse current increases. Higher energy content of the pulse is naturally associated with high heat content, which is capable of removing higher work material. This naturally results in higher material removal rate as the pulse current increases.

4.2 Effect of pulse voltage:

The surface profiles of specimen for differing values of pulse voltage are illustrated in fig 5.7.The center line average roughness (R_a), Skew ness (R_{sk}), Kurtosis (R_{ku}) and Material removal rate (MRR) in respect of differing values of pulse voltage are given in table 4.2.

Table 4.2: **CLA roughness, Skew ness, Kurtosis & MRR for differing pulse voltage**

	CLA Roughness R_a (μm)	**Skewness** R_{sk}(μm)	**Kurtosis** R_{ku}(μm)	**M.R.R** (mg/min**)**
40	**PULSE VOLTAGE** (V) Volts	0.18	2.36	0.9246
50	2.52	-0.12	2.52	2.1279
60	3.38	-0.28	2.86	4.7862
70	4.42	-0.42	3.24	7.1431
80	5.28	-0.16	2.78	7.2591

From the fig 5.7, It is observed that with the increase in pulse voltage the CLA roughness (R_a) also increases for every input pulse voltage. We are aware that the energy content in the spark in EDM is given by the following relation.$E_s = VIT_{on}$ Where, V= pulse voltage, I= pulse current,T_{on} = pulse time on.

From the above relation, it can be seen that the pulse energy increases as the pulse voltage increases. Higher energy content of the pulse is naturally associated with high heat content which is capable of removing higher work material. Thus the craters formed due to the removal of work material are deeper for higher levels of pulse voltages. Such deeper craters formed in series due to the movement of tool form a surface structure of higher roughness at higher pulse voltages. Thus the surface roughness increases as the pulse voltage increases.

The variation of skew ness with that of pulse voltage is illustrated in Fig. 5.8

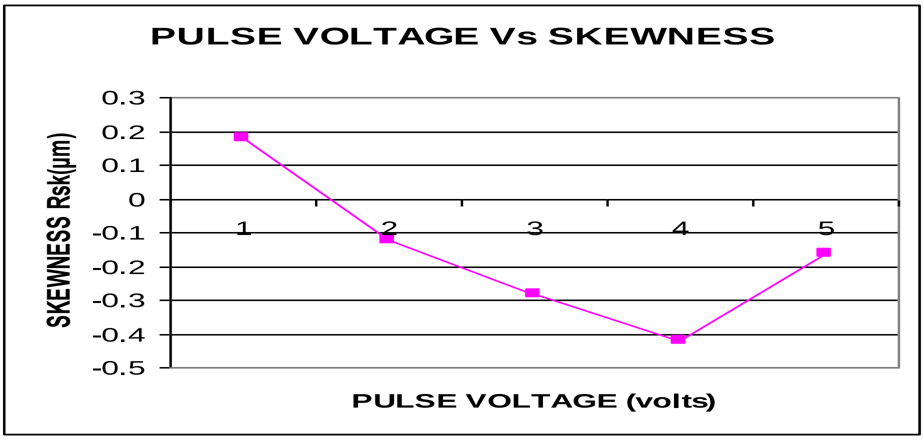
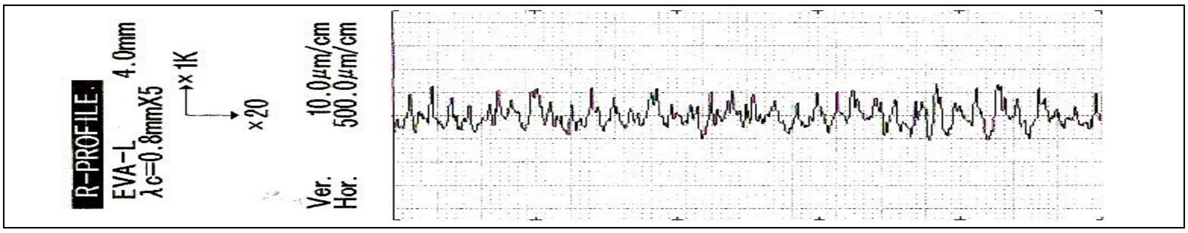
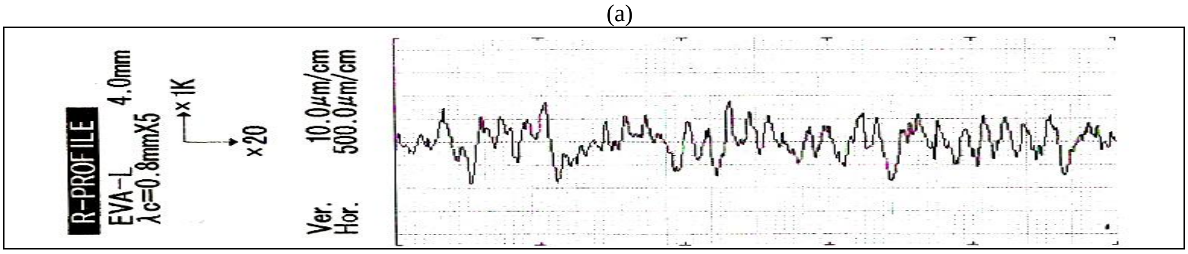


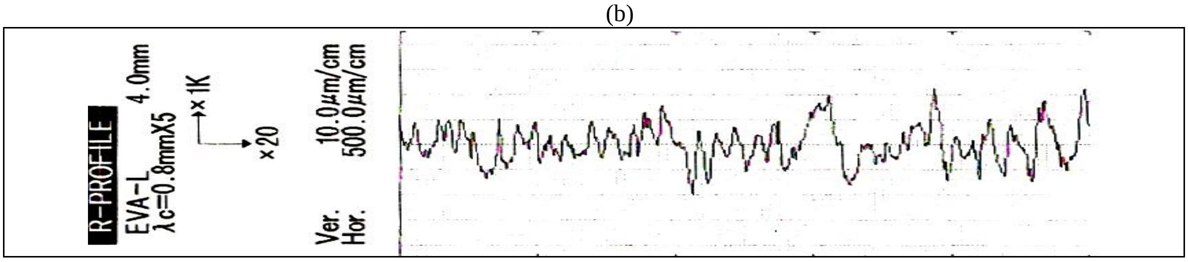
Fig 4.7: variation of skewness with pulse voltage



(a)



(b)



(c)

Fig 4.8 Surface profiles of specimen for differing pulse voltages (a)40 Volts (b) 50 Volts (c) 60 Volts The variation of CLA roughness R_a with the increase in pulse voltage is illustrated in Fig 5.7

From Fig 4.7, it is observed that with the increase in pulse voltage, the skewness decreases up to certain point and then increases with increase in pulse voltage (as we can observe at point 3). As pulse voltage increases then the energy of spark raises up which results in increase in metal removal rate, thus form craters on the work specimen which are deeper. Thus, deeper craters naturally result in valley biased surface structure i.e., negative skew ness. Thus increase in pulse voltage result in surface whose skewness decreases with pulse voltage. However, as the pulse voltage increases beyond certain limit, the material removal mechanism by high-energy content pulses undergoes some modification from the one at lower pulse voltage. At higher pulse voltages, the energy content in the pulse is more. Such high-energy content pulses allow for side sparks besides the regular frontal sparks from the face of the tool. Such side sparks naturally remove the work material, which widens the craters rather than forming deeper craters. Such wide craters result in surface structure whose skewness increases. Thus the skew ness increases as the pulse voltage increases beyond some limit. The variation of kurtosis with that of pulse voltage is illustrated in Fig. 4.9

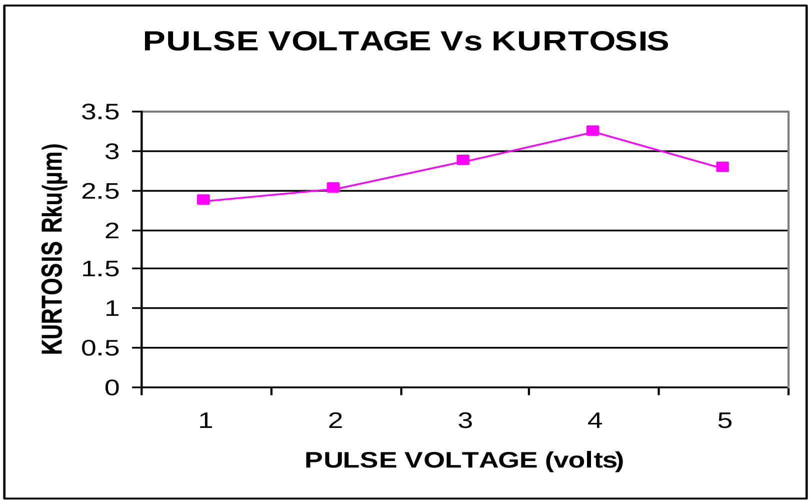


Fig 4.9: variation of kurtotis with pulse voltage

From Fig 4.9, It is observed that with the increase in pulse voltage, the variation of kurtosis increases up to certain point and then decreases with increase in pulse voltage (as we can observe at point 3). Such different behavior of kurtosis as pulse voltage increases can be explained in the similar lines as was the case with variation of skew ness with pulse voltage. The increase in pulse voltage increases the energy content which in turn removes higher work material with craters whose peaked-ness is more. Thus the kurtosis increases as the pulse voltage increases. However as the pulse voltage increases beyond certain limit, the side sparks come into existence which naturally alter the shape of the craters formed on the work surface. Thus the kurtosis decreases as the pulse voltage increases beyond certain limit.

V. CONCLUSIONS

The present work on the effect of pulse current and voltages on the various aspects of surface roughness corresponding to the investigation carried out on SS-410 work piece by copper electrode in Electro Discharge Machining indicates the following.

- Material removal rate increases with increase in pulse current and pulse voltages.
- Surface roughness increases with increase in pulse current and pulse voltages.
- Skewness decreases as pulse current and pulse voltages increase. However the material removal mechanism at high pulse current and pulse voltages modifies resulting in the increase of skewness at very high values of pulse current and pulse voltages.
- Kurtosis increases as pulse current and pulse voltages increase. However the material removal mechanism at high pulse current and pulse voltages modifies resulting in the decrease of kurtosis at very high values of pulse current and pulse voltages.

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