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EXPERIMENTAL INVESTIGATIONS AND MONITORING ELECTRICAL DISCHARGE MACHINING OF INCOLOY800

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ABSTRACT

Precise, dynamic monitoring of spark gap is essential for stable repetition of the discharge during the machining of electrically conductive and difficult-to-machine materials. The process monitoring using acoustic sensor provides set of guidelines for study of electrical discharge machining process (EDM). In the present study, experimental investigations are carried out to monitor EDM process using Acoustic emission. Signal generated from machining area is collected using piezoelectric sensor and processed through data acquisition system. An Attempt has been made to find out effect of peak current, on time gap voltage on acoustic generation level, material removal rate and surface roughness of machining INCOLOY 800. Experimental results confirm that the proposed method provides information of spark column behavior and the machining performance of EDM process. Current found as the significant parameter affecting on machining quality and acoustic level generated. Statistical model developed using dataset can be used to predict the respective parameter. Acoustic level variation monitoring can be helpful for monitoring EDM process stability, surface quality and productivity.

Keywords: *Electrical Discharge Machining, Process monitoring and Acoustic emission.*

1. Introduction

To achieve optimum machining performance in terms to have better quality and productivity in Electrical discharge machining (EDM), selection of proper machining parameters is important. EDM process should be monitored carefully to meet the requirements in product and to optimize the process with respect to cost, productivity and quality. In the present paper, an attempt is made to study EDM process monitoring and acoustic signal generated from sparking gap. Also, significance of variation of input parameter such as current, on time and gap voltage on response input variables namely material removal rate, surface roughness and acoustic signal level is critically evaluated. Acoustic Emission Analysis (AEA) is based on the phenomena that acoustic impulses are emitted during the deformation processes or crack growth in a material. A real-time monitoring technique for the EDM process is to measure the voltage, current and acoustic signals between the electrode and the work piece. The voltage, current and acoustic signals can be used to discriminate the EDM pulses as sparks, arcs, shorts, and open circuits which can be related to the material removal rate (MRR), the surface finish, and the accuracy of the component.

As, EDM is a process for achieving super finish products of conductive materials requires more attentions, but from long decades manufacturers are using trial & error method to achieve the required finish level. Above stated problem can be solved by developing a knowledge-based intelligent machining system between the machining parameters and surface roughness, MRR using machining Acoustic signals of the EDM spark column, which contains information of process. Acoustic Emission (AE) is successfully used for most of the conventional manufacturing process by researchers, it can be also used for EDM process considering uncertain and complex behavior of the spark column.

Using the acoustic signal one can assess the process stability and develop the mathematical model between the machining parameter and surface roughness for prediction for the respective combinations of process parameters. Acoustic level data can be monitored and used for development of strategy of process parameters variation to achieve desired productivity and quality of work piece.

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1.1 Acoustic Emission in EDM and Literature Review

Few literature sites study of the generation of acoustic in EDM and effect of process parameters on response variables. Yusuf K et al, 2005 carried out experimentation for cylindrical copper electrode with steel rectangular work piece and conclude that surface finish has decreasing trend with an raise of the discharge duration. Investigation into effect of electrolytic copper tool electrodes of triangular, square, rectangular and circular geometry to erode medium carbon steel (EN8) work piece was carried out. (M. S Sohani et al, 2009). Study was carried out to study effect of discharge current behavior on the occurrence of the AE waves by means of an optical fiber vibration sensor, controlled pulse improve surface roughness and wear out (A Hirao et. al)

Behavior of detected wave forms by varying discharge duration and waveform by simulated are same, current effects AE waves behavior during discharge (Y. Akematsu et al, 2008). Erosion drops beyond a certain value of pulse on time (K P Rajurkar et al). In µEDM of PCD maximum values of AE signals is proportional to discharge pulse energy (M Mahardika et al, 2008). Sparking frequency above critical value leads to wire breakage in WEDM process (K P Rajurkar et al). Presence of debris can lead to spurious charge, causing the discharge gap to increase, tool dimensions to decrease and machining precision to be reduced in µEDM. (M T Richardson et al, 2008). It is very important to study the combined effect of current, on time, off time, flushing pressure on surface roughness, material removal rate with the help of acoustic emission and its correlation so that useful database can be created. Acoustic Emission Analysis (AEA) is based on the phenomena that sort Acoustic impulses are emitted during the deformation processes or crack growth in a material. In Electrical Discharge machining, it is important to select machining parameters for achieving optimal machining performance.

The purpose of monitoring the process is to optimize the process with respect to cost, productivity, quality etc. The process should be monitored carefully to produce an output that can meet the requirements. The measured signals from machining spark column contain a combination of useful information.

1.2. Experimental Setup

Cu and INCOLOY 800 is selected as a Tool and work piece material respectively. Electrode diameter of 10 mm is taken in experimentation. The experimentation setup is shown in Figure 1. The Piezotron 8152B21SP Acoustic sensor, 100 to 900 KHz with 5125B2 industrial coupler and NI 9234 signal acquisition system, SW Selectable IEPE & AC/DC, 4 Input, 24-Bit, 51.2 kS/s, are being used. Data collection and processing is done using Labview software.

2. Effect of input variables on Response Variables

Material removal is accomplished through spark erosion between a work piece and tool electrode in Electrical discharge machining (EDM) process. Process stability is of great importance to the productivity of the EDM process. Acoustic signals produced by the Electric discharge machining (EDM) contain information about the behavior of the spark column, the eroded material in machining area. This research work investigates the application of acoustic emission (AE) in EDM as a process monitoring technique. To evaluate influence on acoustic emission signal and effect of process parameter on the response parameter experiment are performed.

2.1 Effect of flushing pressure on acoustic level

To find out effect on acoustic level flushing pressure is varied with three different level of 0.3,

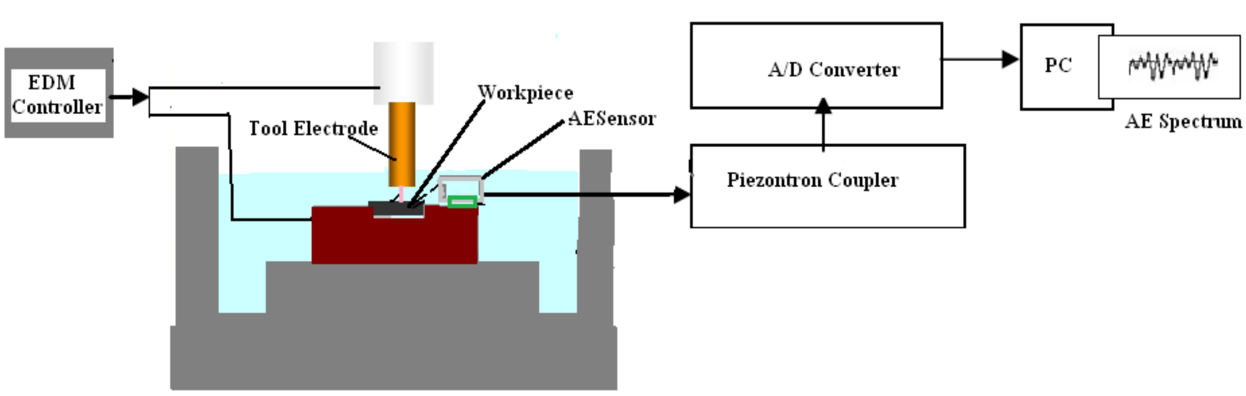

Fig. 1 Acoustic monitoring setup for EDM

0.6 and 0.9 kgf/cm^2 in absence of spark and keeping all auxiliaries off. It is observed that bubble formation of dielectric fluid does not affect actual acoustic emission generated during machining. Based on the experimental findings flushing pressure is selected 0.4 kgf/cm^2 further experimentation.

2.2 Effect of peak current on material removal rate, surface roughness and acoustic level

To find out the significance of current (I) variation on MRR, AE level and surface roughness, five levels of current are selected keeping other parameters as constant. Other constant parameters which are selected as constant to study individual effect of current are depth of cut 1 mm, on time 240 µs, off time 103 µs, duty factor 0.7, and gap Voltage 70 V.

From the experiments it is revealed that current have effect on material removal rate and surface roughness. Experimental and predicted values of response variables using the best fitted model of the response variable are shown in table 1. Developed model to predict results for current variation are shown as equations 1,2 and 3.

$$MRR = 87.33 - \frac{817.90}{I} + 160440.70 \times e^{-I} \quad (1)$$

$$AE\ level = 0.09 + \frac{8.21}{I} - \frac{149.90}{I^2} + \frac{726.78}{I^3} \quad (2)$$

$$SR = 11.57 + 0.00005 I^3 \quad (3)$$

Prediction of MRR, AE level or surface roughness can be made using developed regression model of on time variation.

Table 1 Effect of current variation

Current (I) (Amp.)	MRR (mm^3/min.)		AE Level (V)		SR (µm)	
	Experimental	Predicated	Experimental	Predicated	Experimental	Predicated
9	16.261	16.253	0.1528	0.1527	11.64	11.61
13	24.356	24.778	0.1683	0.1694	11.7	11.68
17	40.320	39.226	0.2097	0.2062	11.76	11.82
21	47.677	48.383	0.2201	0.2235	12.08	12.04
28	58.149	58.120	0.2301	0.2291	12.36	12.36

Predicted percentage error for MRR, AE level and SR are lower than 3% for INCOLOY 800 material.

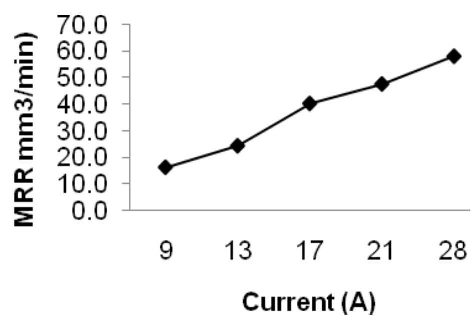

Fig. 2 Effect of Current on MRR

It is observed that MRR is majoraly affected by current as shown in figure 2. In the range 9 amp-13 amp, MRR increases moderately then it increases rapidly between 17 amp-28 amp. Increase in MRR is due to the high energy available at higher current of plasma column in gap.

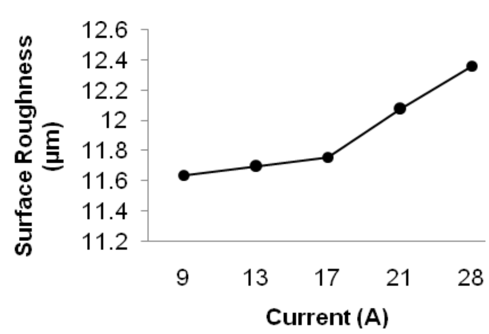

Fig. 3 Effect of Current on Roughness

The roughness of the electric discharge machined surface is associated with the distribution of the craters formed by the electric sparks. The experimental results reveals that for a constant pulse on-time, the surface roughness increases with increasing pulse current, as shown in Figure 3. Therefore, it is possible to infer that a higher material removal rate will result in a rougher electric discharge machined surface. Correlation of current with surface roughness, MRR and acoustic level shows that as current increases MRR and acoustic level increases with increment of surface roughness as shown in figure 2, 3 and 4.

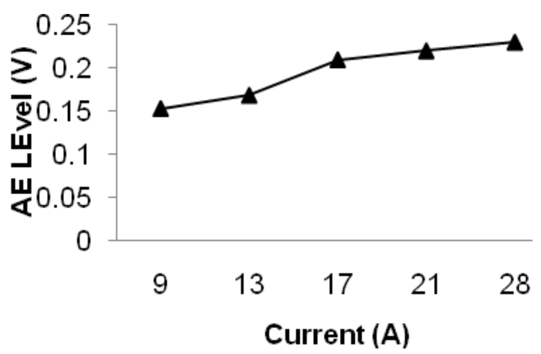

Fig. 4 Effect of Current on AE level

Prediction of MRR, AE level or Surface roughness can be made using developed regression model of current variation. Stability of spark gap can be observed via monitoring acoustic level from the machining area. Acoustic level fluctuations from the observed level give indication of irregularity in the machining area.

2.3 Effect of on time on material removal rate, surface roughness and acoustic level

To find out effect of on time variation on MRR, AE level and surface roughness, the five different level of on time are selected keeping other parameters as constant. The values of other parameters which were made constant are current 17 A, depth of cut 1 mm, on time 240 µs, off time 103 µs, duty factor 0.7 and gap voltage 70 V.

Table 2 Effect of on time variation

	MRR (mm^3/min.)		AE Level (V)		SR (µm)	
On time (µs)	Experimental	Predicated	Experimental	Predicated	Experimental	Predicated
40	18.489	18.598	0.2039	0.2038	11.7	11.69
55	21.47	21.063	0.2138	0.2138	11.89	11.89
70	24.867	25.317	0.2149	0.2148	12.14	12.12
85	31.999	31.846	0.215	0.2150	11.97	11.97
100	26.541	26.541	0.2165	0.2164	11.05	11.04

Experimental value and predicted value using the best fitted model of the response variables is shown in table 2 for on time variation as input variable. Developed model to predict results for on time variation are shown as equations 3,4 and5.

$$MRR = 17.05 + 0.00002{T_{on}}^3 \quad (4)$$

$$AE\ level = -3.91 + 2.89\log T_{on} - 0.67\log {T_{on}}^2 + 0.05\log {T_{on}}^3 \quad (5)$$

$$SR = 14.37 - 0.169SR + 0.003 \times SR^2 - 0.00005SR^3 \quad (6)$$

Percentage error for MRR, AE level and SR between experimental and predicted values are lower than 2 % for INCOLOY 800 material. Prediction of MRR, AE level or surface roughness can be made using developed regression model of on time variation.

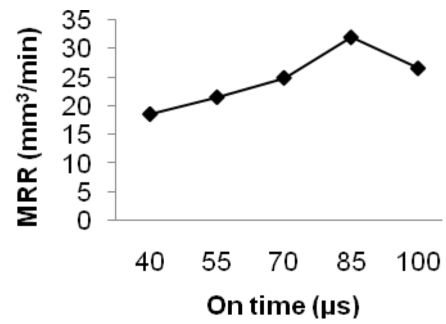

Fig. 5 Effect of on time on MRR

A nonlinear relationship between pulse on time and MRR is observed as shown in figure 3. MRR increases as the value of Ton increases up to 85 µs. The rate of increase in value of MRR is more for range of Ton 70µs -85 µs. With further increase in pulse on-time from 85 µs -100 µs, the MRR decreases slightly. This may be attributed to reason that with high pulse on time i.e. 100µs, more material gets melted at the tool work piece interface, which require proper flushing time but as the value of pulse off time is too short comparative to pulse on time so there is not enough time for the flushing to clear the debris from the inter-electrode gap between the tool and work piece, hence arcing may takes place which accounts for decreasing the MRR.

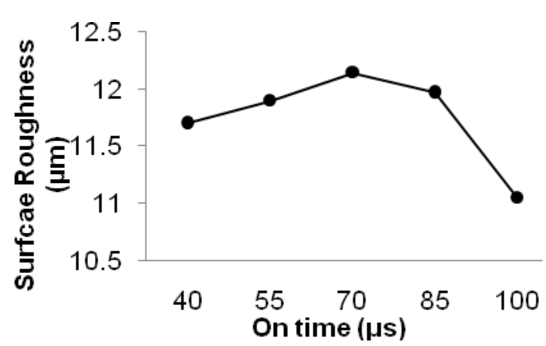

Fig. 6 Effect of on time on Roughness

As on time increases SR increases upto 70 µs on time the it decreases as shown in figure 6. Increment of on time keeping duty factor constant reduces off time, hence after certain on time debris removed earlier do not flush way properly resulting into arcing causes les poor surface finish. Acoustic level do not have significant trend in variation with on time increment. As per literatures as with increase of current and on time MRR and surface roughness are having reverse behavior, so acoustic level can be intermittent to monitor the process to get optimum value of both MRR and surface roughens. Intermittent level acoustic level can be found out form study, at which both are at desired maximum value. If acoustic level changes from that certain level respective current or on time should be controlled during machining.

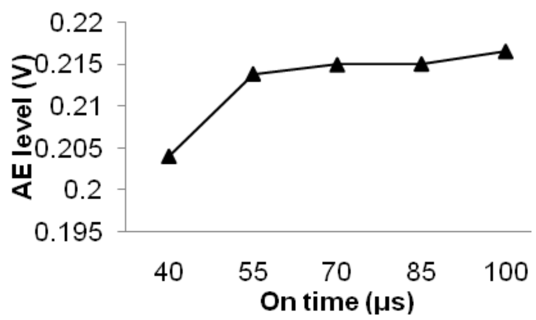

Fig. 7 Effect of on time on AE level

From the acoustic spectrum it is observed that too low on time have narrow acoustic spectrum, while high on time give wider spectrum in which clear identification of one spark after completion of other can be clearly identified.

2.4 Effect of gap voltage on material removal rate, surface roughness and acoustic level

To find out effect of gap voltage variation on MRR, AE level and surface roughness five different level of gap voltage was selected keeping other parameters as constant. Other parameters which were made constant are current 17 A, depth of cut 1 mm and duty factor 0.7.

Experimental value and calculated value using the above best fitted model of the response variable is shown in table 3 for Gap voltage as input variable. Statistical model developed for various process parameters and response variable are as shown as equation number 7, 8 and 9.

Table 3 Effect of Gap Voltage variation

	MRR (mm^3/min.)		AE Level (V)		SR (µm)	
Gap Voltage (V)	Experimental	Predicated	Experimental	Predicated	Experimental	Predicated
40	33.909	33.909	0.201	0.2009	11.61	11.60
55	45.367	44.7133	0.211	0.211	11.85	11.8
70	37.639	40.199	0.217	0.216	12.35	12.31
85	40.87	37.855	0.218	0.218	12.41	12.44
100	35.378	36.485	0.219	0.218	12.39	12.37

$$MRR = 32.91 + \frac{35683.9}{Vg^2} \quad (7)$$

$$AElevel = 0.1332 - 0.0026Vg - 0.00005\,Vg^2 \quad (8)$$

$$SR = 7.157 + \frac{1089.86}{Vg} - \frac{70367.50}{Vg^2} + \frac{1355845.209}{Vg^3} \quad (9)$$

Percentage error for experimental and predicted value for MRR, AE level and SR are lower than 10 % for INCOLOY 800 material. Prediction of MRR, AE level or Surface roughness can be made using developed model of gap voltage variation. It helps to find out desired value of gap voltage to get the desired output.

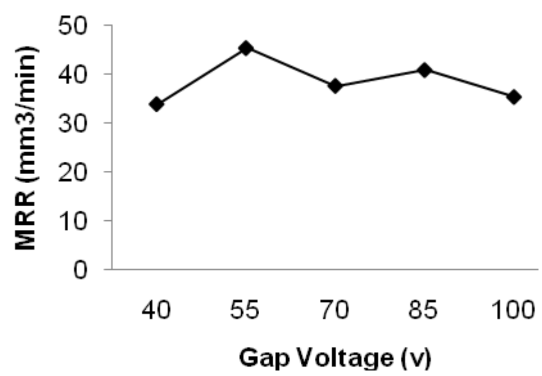

Fig. 8 Effect of gap voltage on MRR

As gap voltage increases MRR increases as shown in figure 8 for certain level then decreases. Acoustic level have significant trend in variation with gap voltage increase. Figure 8 represents variation of MRR w.r.t. voltage. There is slight increase MRR from 40 V to 55 V and sharp decrease from 55 V to 70 V. Decrease in MRR with increase in voltage lies between above two in range of 55 V-70 V. Increase in voltage leads to increase in spark energy. More spark energy means more material removal in the presence of suitable values of remaining process parameters.

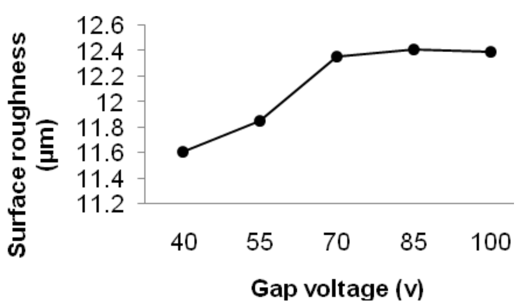

Fig. 9 Effect of gap voltage on Roughness

Experimental results reveals that for a constant pulse on-time, the surface roughness increases with increasing pulse current and it is noticed that for a constant current, the surface roughness decreases with increasing pulse on-time. From the acoustic spectrum it is clearly observed that high gap voltage result in stronger sparking resulting in higher acoustic level which is also reflected with surface roughness increment. If Predicted value AE level using set of database is observed at the respective Current, on time or gap voltage helps to monitor MRR and SR. In few of the experiments irrespective of peak current level, acoustic level decreases reflecting the presence of debris. EDM process variable peak current has a positive effect, and it can be main parameter to be controlled in required limit.AE level deviation from desired level indicates the process fluctuation and process abnormality and provide signal for improvement.

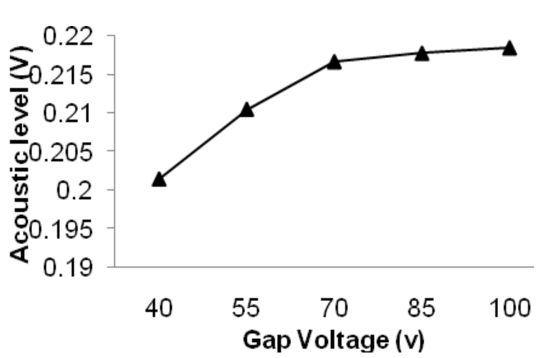

Fig. 10 Effect of gap voltage on AE level

To get desired productivity and quality in EDM process, Material removal Rate (MRR) and Surface roughness need to be controlled, which can be achieved using optimum process parameters combination and monitoring acoustic level of machining area. Any operator who is intended to get desired MRR and SR can predict Acoustic level to be observed during machining, with the help of following correlation.

2.5 Correlation coefficient

Correlation coefficient value calculated using regression analysis is shown in table 4 for relative evaluation of the process parameter effect on response variables. Correlation coefficient values for peak current show significant effect on MRR, acoustic emission level and surface roughness as compared to other process parameters.

Table 4 Correlation coefficient for Prediction

Factor	Response	Correlation Coefficient
Current	MRR	0.9815
Current	AE	0.9356
Current	SR	0.9666
On time	MRR	0.8191
On time	AE	0.8220
On time	SR	-0.4570
Gap Voltage	MRR	-0.0537
Gap Voltage	AE	0.9069
Gap Voltage	SR	0.9098

3. Conclusion

Process monitoring with the help of acoustic emissions technique have growth in various manufacturing processes. Electrical discharge process monitoring using acoustic sensor provides spark column information in electrical discharge machining process. Individual effect of input variable on surface roughness increase or decreases can visible in acoustic level variation. Thus, monitoring acoustic emission from sparking area can reveal information of stability of electrical discharge machining. Debris is formed in the machining region and if not flushed out from machining gap, controllers sense it as material and make spark in that region resulting in poor surface quality and lesser productivity.

EDM Process parameters namely pulse on time, current and voltage affect the material removal rate. It increases with increase in pulse on time up to a certain then decreases. Increase in current provide an initial increase in MRR but further increase in current results in decrease in MRR. It increases with increase in voltage. As the peak current increases, energy intensity available in spark gap increase with high discharge pulse energy resulting high acoustic generation. Positive increment of correlation coefficient helps to predict the behavior of output.

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