Parametric Investigation and optimization of Near-Dry Electrical Discharge Machining

H Pandey1*, K Dhakar2, A Dvivedi2 and P Kumar2

1Department of Mechanical Engineering, Graphic Era Hill University, Bhimtal. UK 263136, India
2Mechanical and Industrial Engineering Department, Indian Institute of Technology Roorkee, UK 247667, India

Received 11 November 2013; revised 21 October 2014; accepted 15 May 2015

This study investigates near-dry Electric Discharge Machining (EDM) in order to achieve higher Material Removal Rate (MRR), lower Tool Wear Rate (TWR) and Better surface finish than conventional EDM on High Speed Steel (HSS) workpiece. Taguchi L27 orthogonal array was used for conducting experimentation. The experiments have been conducted by mixing of limited quantities of water with high pressure air (air-mist). This paper presents a relatively simple device to be used for applying the near-dry EDM. The near-dry EDM does not produce toxic fumes so called Environment friendly machining process for the applied operating conditions, the near-dry electrical discharge machining presents some advantages regarding the machined surface quality and the electrode tool wear, in comparison with the machining that uses liquid dielectric. The effect of different process parameters like applied current, duty factor, gap control, sensitivity, tool lift was analyzed on MRR, surface finish and tool wear rate.

Keywords: Near-dry EDM, HSS, Taguchi L27 orthogonal array, ANOVA

Introduction
Electrical discharge machining (EDM) is a well-known phenomenon to machine electrically conductive materials. EDM has very wide area of applications in defence, aerospace, automobile and medical industries. EDM is also being used for producing complex cavities, which are otherwise difficult to create by conventional machining processes1. It uses thermolectric source of energy to machine any electrically conductive material irrespective of its complex profile with low cost makes process more prominent technology for commercial purpose. In EDM the process of material removal by controlled erosion through a series of electric sparks when a suitable gap established between tool and workpiece. Two electrodes (i.e. anode and cathode) are immersed in dielectric fluid and connected to power source. Hydrocarbon and de-ionized water are very common type of liquid dielectric although gaseous and liquid gases mixed dielectrics are also used in certain cases2. However, high electrode tool wear, low MRR, poor surface finish, environmental concern due to dielectric and thermal damage restrict its wider area of application3-4. Dry EDM is one of the substitutes of this process which uses gas as a dielectric medium. Dry EDM shows advantage over conventional EDM as it provides low tool wear and reduce environmental concerns as it does not produce toxic content. But Surface finish is not improved much due to improper flushing and debris deposition. MRR is very less when using non-oxygen gases4. As an alternative method, the near-dry EDM uses liquid-gas mixture as the dielectric medium. The liquid content in the mist media helps to solidify and flush away the molten debris and hence the debris deposition is reduced in near-dry EDM. Tanimura et al.5 introduced the near-dry EDM in 1989 after this Kao et al.6 conducted experiments on this process using near-dry wire EDM. It reveals that near-dry EDM has the advantage in finish operation with low discharge energy considering. Its lower TWR than wet EDM and better surface finish quality than dry EDM3. Near-dry EDM is used as a super finishing process. The mirror-like surface finish with 0.32 μm Ra was achieved using the kerosene mist and copper infiltrated graphite electrode with 100 μJ pulse energy7. Near-dry EDM was proven beneficial for the finishing operation. Liquid phase dispersed in the gas medium is hypothesized to enhance the electric field and thus results in a large discharge gap distance and a stable...
discharge at low energy input. Nitrogen and helium gases could prevent the electrolysis and yield better surface finish in near-dry EDM. Reducing the discharge energy input by reducing current, reducing pulse on, and increasing pulse off is the key to further increases the surface finish in near-dry finishing EDM. Huang et al. studied the behaviour of kerosene and water as dielectrics on the EDM characteristics of Ti–6Al–4V and build results that material removal rate of Ti–6Al–4V alloy is larger whereas the comparative tool wear quantitative relation is lower once exploitation water than kerosene. The main aim of the present work is to investigate and report the effect of current, duty factor, sensitivity, gap control and lift setting on near-dry EDM of high speed steel (HSS). The optimal process parameter settings are also determined.

Experimental Details

Experimental setup
The experiments were conducted on EMS 5030 die sinking EDM by Electronica India, equipped with an additional attachment for dielectric mixing on the tool holder head. The dielectric fluid mixture was delivered by a dielectric mixing unit which was mounted on the tool holder device. Deionized water was supplied to the dielectric mixing unit at a constant flow rate. Air was supplied to the mixing unit at a high pressure with constant flow rate, subsequently this air-mix dielectric fluid was injected through tubular electrode between the inter electrode gap (IEG). The flow rate of the liquid dielectric was constantly maintained at 3 ml/min while changing the compressed air pressure from 3 to 9 bar. In the present work, hollow copper tool electrode of external diameter 8 mm and internal diameter 5.5 mm has been used to machine HSS workpiece. A mixture of distilled water and compressed air was used as dielectric medium injected through the tubular electrode at constant pressure between the inter electrode gap (IEG).

Design of experiments
To investigate all the possible combination of parameters is a complicated, time consuming and costly process. On account of this various design-of-experiments (DOE) methods are widely used to reduce these problems. DOE investigate all possible conditions in an experiment involving multiple factors. DOE methods set up the efficient experimental schedule and produce a statistical analysis to indicate quickly and easily what parameters are important for the final results. Table 1 shows different process parameters which were used for experimentation. Taguchi L_{27} orthogonal array was used for designing the experiments in this study.

Results and Discussion
Experiments performed by using the parametric approach of the Taguchi’s method. Taguchi L_{27} orthogonal array was used in this study for investigating and optimizing the process parameters of near-dry EDM. Pilot experimentation was conducted using O-F-A-T to select ranges of process parameters. The effects of individual near-dry EDM process parameters, on the quality characteristics MRR, TWR and SR have been discussed in this section. The analysis of variance (ANOVA) of raw information is taken out to recognize the significant variables and to measure their effects on the response characteristics. The most favourable values of process variables in terms of mean response characteristics are prepared by analysing the response curves and the ANOVA tables.

<table>
<thead>
<tr>
<th>Variable Parameters</th>
<th>Code</th>
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<tr>
<td>Current (A)</td>
<td>A</td>
<td>6</td>
</tr>
<tr>
<td>Duty factor</td>
<td>B</td>
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</tr>
<tr>
<td>Sensitivity</td>
<td>C</td>
<td>3</td>
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<td>Tool Lift</td>
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<td>4</td>
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<tr>
<td>Gap Control</td>
<td>E</td>
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<td>Air and deionized water</td>
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<td>Pressure</td>
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<td>Fluid flow rate</td>
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<td>3 ml/min</td>
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<tr>
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<td>Anti-Arcing</td>
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<td>4</td>
</tr>
<tr>
<td>Spark</td>
<td>:</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 1—Process parameters and their Levels used for experimentation
value the intensity of the spark decreases thus MRR decreases. It has been observed during the experiments, MRR increases with increase duty factor at certain level after that a sudden drop in MRR was observed. It may be due to improper flushing provided during the high pulse on time. So that debris does not remove from hole and create recast layer.

Effect of various process parameters on SR
At low discharge energy near-dry EDM gives best surface finish. High current or high discharge energy causes thermal damage and burr formation on the work surface. High value of gap setting also decreases MRR as shown in Figure 2. It was attributed that higher gap setting provides efficient flushing at IEG. It results in eliminates debris accumulation on machined surface.

Effect of various process parameters on TWR
It was observed that TWR was maximum with higher current (Figure 3). It occurs due to higher discharge energy produces high temperature between tool electrode and workpiece. It results in increase in TWR. TWR increases with increase duty factor at certain level after that TWR decreases, because of at high pulse on time machining time increases which cause of improper flushing so that some debris attached on the tool tip.

Parametric Optimization of Near-Dry EDM
After completing experiments and analysing the entire graphical results next step is to optimize the parameters with the help of ANOVA.

Optimization of MRR
From the experimental data of MRR the ANOVA table was generated (Table 2). Higher is better approach is chosen for MRR. The optimum value of MRR was determined with the help of selected parameters as shown in equation 1.

\[
\overline{\text{MRR}_{A3B2C2D1E1}} = \overline{T} + (A_3 - \overline{T}) + (B_2 - \overline{T}) + (C_2 - \overline{T}) + (D_1 - \overline{T}) + (E_1 - \overline{T}) \quad \ldots (1)
\]

where \( \overline{T} \) is the average values of the MRR on calculating \( \overline{T} = 1.14 \) mm\(^3\)/ min Confidence interval can be calculated as C.I. = \( \sqrt{F(1, f)\frac{1}{n} + \frac{1}{R}} \)

The F-ratio at a confidence level of \((1-\alpha)\) against DOF 1 and error DOF f and V= error variance, n is the effective number of replications (n = 1).

where,
\[ N = \text{Total no of result} = 27 \times 3 = 81 \]
\[ R = \text{Sample size for confirmation experiment.} \]
On calculating the following values, the data generated as follows:
\[ n = 7.36, \ R = 3, \ F_{(1, 16)} = 4.49, \ C.I. = 4.042, \overline{\text{MRR}} = 12.38 \]

Now at 95% confidence interval the optimum MRR is: \( [\overline{\text{MRR}} - \text{C.I.}] < \text{MRR} < [\overline{\text{MRR}} + \text{C.I.}] = 7.89 < \text{MRR} < 16.87 \)

Optimization of Surface roughness
Surface roughness was optimized on the basis of experimental data. Table 3 shows analysis of variance for surface roughness. On the basis of experimental data of surface roughness the value of optimization was generated. Smaller is better approach was used for surface roughness. Calculations were done using the equation such as in the previous case. The result found as follows:
\[ n = 7.36, \ R = 3, \ F_{(1, 16)} = 4.49, \overline{\text{T}} = 1.18\text{Ra}. \]
\[
\overline{\text{SR}}_{A1B1C5D1E2} = \overline{T} + (A_3 - \overline{T}) + (B_2 - \overline{T}) + (C_2 - \overline{T}) + (D_1 - \overline{T}) + (E_1 - \overline{T}) \quad \ldots (2)
\]
Conclusions

In this study, an attempt is made to machine High speed steel work material using near-dry electric discharge machining (NDEDM). Taguchi’s L27 orthogonal array is chosen to design the experiment for maximizing MRR and minimizing TWR by considering the effect of various parameters like applied current, duty cycle, sensitivity, gap, and lift as the parameters. ANOVA results shows that which parameter is most effective and which is non-effective in this experiment. The experiments were conducted under various parameters settings of analysis of L27 orthogonal array was performed in Qualitek 4.0 software.

1. MRR in the near-dry EDM was 62% higher than the conventional EDM. It can also be further improved by using rotary tool electrode and some changes in dielectric medium.

2. TWR was very less in near-dry EDM and 40% lesser than conventional EDM that was almost negligible.

3. Surface roughness in near-dry EDM is much better than in conventional EDM.

References