A Review on thermal analysis and modelling techniques of Die Sinking Electric Discharge Machine

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Abstract- Electric Discharge Machining also known as spark machining is widely used in production where required shape is obtained using sparks. Material is removed from the work piece by a series of rapidly frequent current which forms discharge or spark between electrode and work piece, separated by a dielectric liquid. This paper presents a review based on different material, parameters and various optimization methods used to estimate the temperature distribution and thermal stress analysis. In this paper review is presented based on different parameters, various methods and optimization techniques applied by others to estimate the thermal investigation and distribution of temperature. Also the effect of thermal stress on the work piece and tool (electrode) during machining is discussed.

Index Term: Electrical Discharge Machining (EDM), Material Removal Rate (MRR), Tool Wear Rate (TWR), Finite Element Analysis (FEM), Artificial Neural Network (ANN), Thermal Stress, Temperature distribution.

1. Introduction:

Worldwide integration and development is making the manufacturers to empower and formulate in the production of quality products to deliver the best. Thus, the research in been focused towards the high speed machining process involving Computer Numerical Controlled Machines and unconventional Machining such as Electron Discharge Machining (EDM). It is difficult to engrave hard materials as steel from conventional machines. EDM is the solution for such materials. EDM'S capability of using thermal energy to machine metals despite of hardness has been its idiosyncratic advantage in the manufacture industry. That's the reason EDM is playing a well-known role in manufacturing industries as automotive, die and mould making, aerospace and surgical components [1].

EDM is a machining process for removing material by action of electric sparks on electrically conductive materials. A small gap is to be located between the work piece and the electrode immersed in a dielectric liquid. Local thermal effect of a discharge is the reason of erosion.

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The thermal effect involves heat conduction, energy distribution, melting, evaporation, ionization, formation and collapse of gas bubbles during machining when spark is generated [2]. Spark forms when the voltage across the gap between the electrode and work piece becomes high, and acceleration of the electrodes and positive ions forms a discharge channel. At this moment high pressure and temperature is developed and metal is melted which is called erosion [3].

2. Tool Material:

Tool material should be selected such that it would not endure much tool wear while machining. There should be less melting to tool while spark is generated. Thus the tool material should have properties as: Higher density & High melting point, High electrical and thermal conductivity [4]. Electrode materials which are commonly used in the industry are: Graphite, Copper, Brass, Tellurium (copper 99% Cu + 0.5%Tellurium). A comparative study of using copper and graphite electrode with Die Sinking EDM was analysis and found that graphite electrode is more encouraging than copper electrode for machining of steel work piece for performance parameters as MRR and TWR. The cost of machining material from graphite electrode is less than other electrode [5]. In another study analysed that graphite electrodes are best suitable for lower values of parameters (current, impulse duration) and mainly for finishing work as graphite electrode produces better surface finish due to lower MRR and copper electrodes are suitable for high metal removal process where finish requirements are not considered [1].

3. Work Material:

Selecting the work material for machining is a important task which directly effects the performance. The work done on various materials is as following. On AISI 4140 grade steel alloy, the study of optimized settings of key machining factors has been done using central composite design which results as increase in voltage results in higher MRR also increase in spark gap decreases the MRR[6]. While when Stainless Steel and En41b is machined with copper electrode, increasing the current results increase in power and temperature which directly increase the MRR.

Ceramic material Titanium Di-Bromide TiB2 which have exceptional mechanical properties as hardness, abrasion resistance and high melting point above 2000 ^{o}C and also good thermal and electrical conductivity. The applicability of EDM in manufacturing of TiB2 with copper electrode is discussed and resulted that pulse time parameters have an effective role in increasing MRR. The longer the duration of pulse time increase the carbon deposition on electrode surface and reduce the TWR[7].

The demand for advance materials as Nickel based super alloys GH4169 used in aeronautical applications and turbine component: Ti-6Al-4V alloys used in aeronautical applications, aluminium based metal matrix composites having potential for advanced structural applications due to high specific strength as well as good elevated temperature resistance in increasing day by day with advancement. [8] They presented Die sinking EDM of Ni-Ti alloys simulation to investigate the thermal damage mechanism with the progression of random discharges. An model accounting for random discharge phenomenon was successfully implemented in ABAQUS to simulate massive random discharges.

Material removal process in EDM occurs due to thermal departure and melting in the absence of oxygen so that the process can be controlled and avoid oxidation. Surface conductivity of the work piece is decreased because of oxidation which effects machining. Hence, dielectric fluid is used to provide an oxygen free machining environment. It should ionize when electrons collide with its molecule and also have enough dielectric resistance so that it couldn't breakdown. The dielectric fluid plays an important role because of following points: It helps in quenching the spark, cooling the work and tool electrode. It takes away the removed metal along with it while machining.

4. Parameters of EDM:

4.1. Process or Input Parameters: These parameters are experimented to get better results. Analysis of performance parameters in done with variation in these parameters. So the better optimization of process parameters would yields in better performance of EDM process [9].

1. Spark On-time (pulse time) (µs): The time duration the current flows to the machining operation. The more the pulse time, the more the MRR. The duration of time the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is controlled by the peak current and the length of the on-time.
2. Spark Off-time (pause time) (µs): The time duration between the sparks. In the time the melted material either solidify or wash away from the arc gap with the flushing effect of die electric fluid. This parameter is to affect the speed and the stability of the cut. Spark will cause unbalanced if off time is less.
3. Arc gap (Spark gap): The Arc gap is distance between the electrode and the electrically conductive work piece. Spark gap can be maintained by servo system.
4. Discharge current (current Ip): The current which is followed to flows for machining of EDM to create the spark is called Discharge current which is directly proportional to the MRR.
5. Discharge Voltage (V): It is a parameter measured in volt and also effect to the material removal rate and allowed to per cycle.
6. Duty cycle (τ): This parameter is calculated by dividing the on-time by the total cycle time (on-time pulse off time).
7. Diameter of electrode (D): The electrode Diameter is also a process parameter. So the tool diameter is selected in a way get good performance parameter.
8. Over cut: It is a clearance per side between the electrode and the work piece after the machining operation.

4.2. Performance or Output Parameters:

Material Removal Rate (MRR): The more the MRR, The better the performance. Material removal rate was calculated by using the following formula:

MRR =Volume/time (mm^3/min)

Where V is volume of material removed and t is the mach.

Tool Wear Rate (TWR): The less the TWR, the better the performance. Electrode or tool wear rate is calculated by using the following formula:

EWR = (E_b- E_a) (g)/t (min)* density (g/mm^3) (mm^3/min)

Where E_b and E_a are the weights of electrode material before and after machining, and t is the machining time, the weights of the electrodes were measured using a balance.

5. Modelling and Optimization:

It is essential to produce any product with good value at minimum cost. To achieve this objective, the influence of various process parameters have been studied, which improves the performance of EDM by many researchers. The modelling methods are:

5.1.Mathematical Model: It is the most useful and modelling technique developed to obtain the:
The best working conditions of process parameters (peak current, duty factor, wire tension and water pressure) is achieved by correlating the interrelationship of them, to obtain MRR and TWR while machining the material in EDM [10].

5.2.Simulation: Simulation is the preliminary analysis for the selection of process variables with the help of computer systems by which thermal stresses are estimated. Properties of the material are entered to the simulation software which does calculations, replications at their end and predicts the behaviour, characteristics, functions, breakage indicators of the material, which helps in analysis of the process.

5.3.Taguchi Technique: To study the performance characteristics of machines , literature reveals that the Taguchi technique is the most effective modelling method which developed designs for studying variation.[11] They calculated Material Removal Rate (MRR) and Surface Roughness (SR) using Taguchi experimental design with Work material Precipitation Hardening Stainless Steel (PH Steel) machined with copper tungsten electrode. [12] identified the variations in performance parameters surface roughness, Material removal rate and tool wear rate on work piece Mild steel with copper electrode an optimal set of process parameters is achieved using Grey Relational Analysis, a Taguchi method. [13] Used fractional factorial method developed by Taguchi for optimizing material removal rate using EDM with copper–tungsten electrodes. A new approach of using black layer for improving EDM performance was introduced. They said that the percentage of carbon in the 'black' layer is very important in the improvement of the EDM performance.

5.4.Fuzzy Logic: Fuzzy logic is also called multivalved logic, which is based on theory of fuzzy sets which relates to material properties with set of boundary conditions. The Fuzzy Logic model developed is compared and analysed with optimization parameters. Machining parameters in EDM was selected using fuzzy logic approach. [14] developed a fuzzy model based on the electrical machining of tungsten carbide and analysed that that the MRR and roughness is proportional to pulse duration and discharge current. And TWR is inverse proportional to pulse duration and discharge current.

5.5.Artificial Neural Networks (ANN): In modelling of machining parameters ANN is used either independently or with blend with other algorithm. The thermal analysis while machining in EDM is a complex phenomena, and mathematical consideration of it is very difficult. Therefore prediction of parameters as MRR, TWR when compared with experimental result shows wide variations. The method of variation called ANN. An attempt is to be made to develop an artificial feed neural network for prediction of parameters. The optimum machining process parameters, as crater cavity, MRR and TWR (tool wear rate) are determined by the Intelligent Process Model with FEM and ANN[15]. The ANN models are used to produce crack shapes and surface roughness and Feed forward with Back propagation technique to predict MRR.

5.6.Response Surfaceness Methodology (RSM): How to deal with several responses simultaneously is the objective of this technique, Central Composite Designs (CCD) and Box-Behnken Designs as two of the major Response Surface Design techniques. [4] presented a thermal-structural model to analyze the process parameters and their effect on material removal rate, tool wear rate and residual stresses on work piece in Die sinking EDM machine. Work material used -D2 steel and tool material was-Brass. [9] A Box-Behnkin design of response surface methodology is adopted to collect data for analysis. Response Surface Methodology (RSM) technique is used to analyse input parameters as to check the quality of the surface obtained in EDM and other output parameters.

5.7.Finite Element Analysis: [16] presented the development of thermo physical model (Work material used for machining was steel and tool material was Copper) for Die sinking EDM process using FEM. Gaussians distribution of heat flux equation was used for numerical analysis of single spark operation, based on spark radius equation based on discharge current, latent heat of melting etc to predict the crater cavity and MRR. [17] presented the study of EDM simulation through an numerical model based on the FEM with tool steel AISI D2 as work material and graphite as tool, which discredited by the finite differences method and simulated numerically using a code developed on MATLAB software to find the temperature allotment and MRR. [18] Investigated the sensitivity analysis of EDM machining parameters using ANSYS probabilistic design system on AISI 1045 tool steel and copper as tool. The temperature distribution and the MRR are predicted by the FEM deterministic analysis. Experiments are investigated to validate the FEM model.

5.8.ANOVA: An ANOVA test is a way to find out if survey or experiment results are significant. It help us to figure out if you need to reject the null assumption or accept the alternate assumption. ANOVA method is used with the help of software to analysis the influence of input process parameters on output response. The input parameters are optimized in order to obtain maximum output parameters and the experimental results are validated by confirmation tests.

Conclusion:

The development of EDM has brought many improvements in machining process in recent years. A decisive study on various research works is presented and following observations are made based on this review work. Analysis of using different tool and work piece material is placed with modelling techniques. The objectives of optimization is: to boost the potential of machining performance, to produce better product, and to have better working condition and technique to device new materials through the latest optimization technique used in the EDM processes to Maximize the MRR, reduced the TWR or EWR, improve the Surface Roughness and Surface quality.

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