Process Parameter Optimization of WEDM Process for Machining D2 Tool Steel

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Abstract - The study presents an investigation of wire EDM on metals difficult to machine. Accompanying the development of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing. Wire EDM machines are used to cut conductive metals of any hardness or that are difficult to cut with traditional methods. The D2 tool steel material is extensively used for hot-work forging, extrusion, manufacturing punching tools, mandrels, mechanical press forging die, die-casting dies, aircraft landing gears etc. The objective is to study the effect of current, voltage, pulse on/off time and wire tension individually on the final outcome i.e. cutting rate, surface roughness (Ra) and dimensional deviation to establish the mathematical models relating the performance measures and input parameters by regression analysis. Response surface methodology (Central Composite Design) will be used to carry out the experiments. Statistical methods will be used to estimate relation between output parameters and input parameters. Optimization of input parameters will be carried out by using Grey relational analysis (GRA). This method is chosen because it can perform analysis of more than one factor at a same time while reducing number of experiment which indirectly reduces cost and time in finding optimal parameter.

Key Words: Wire electrical discharge machining (WEDM), gap voltage, discharge current, pulse on/off time, material removal rate (MRR), surface roughness.

1.INTRODUCTION

Accompanying the development of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing. Nevertheless, such materials are difficult to be machined by traditional machining methods. Hence, non-traditional machining methods including electrochemical machining, ultrasonic machining, electrical discharging machine (EDM) etc. are applied to machine such difficult to machine materials. WEDM process with a thin wire as an electrode transforms electrical energy to thermal energy for cutting materials. With this process, alloy steel, conductive ceramics and aerospace materials can be machined irrespective to their hardness and toughness. Furthermore, WEDM is capable of producing a fine, precise, corrosion and wear resistant surface. Its broad capabilities have allowed it to encompass the production, aerospace and automotive industries and virtually all areas of conductive material machining. This is because WEDM provides the best alternative or sometimes the only alternative for machining conductive, exotic, high strength and temperature resistive materials, conductive engineering ceramics with the scope of generating intricate shapes and profiles

WEDM is considered as a unique adoption of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM utilizes a continuously travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05-0.30 mm, which is capable of achieving very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts. During the WEDM process, the material is eroded ahead of the wire and there is no direct contact between the work piece and the wire, eliminating the mechanical stresses during machining. WEDM has tremendous potential in its applicability in the present day metal cutting industry for achieving a considerable dimensional accuracy, surface finish and contour generation features of products or parts. Moreover, the cost of wire contributes only 10% of operating cost of WEDM process. The difficulties encountered in the die sinking EDM are avoided by WEDM, because complex design tool is replaced by moving conductive wire and relative movement of wire guides.

1.1 Fundamentals of Wire Electrical Discharge Machining (WEDM)

Wire electrical discharge machining (WEDM) technology has grown tremendously since it was first applied more than 30 years ago. In 1974, D.H. Dulebohn applied the optical line follower system to automatically control the shape of the components to be machined by the WEDM process. By 1975, its popularity rapidly increased, as the process and its capabilities were better understood by the industry. It was only towards the end of the 1970s, when computer numerical control (CNC) system was initiated into WEDM, which brought about a major evolution of the machining process.

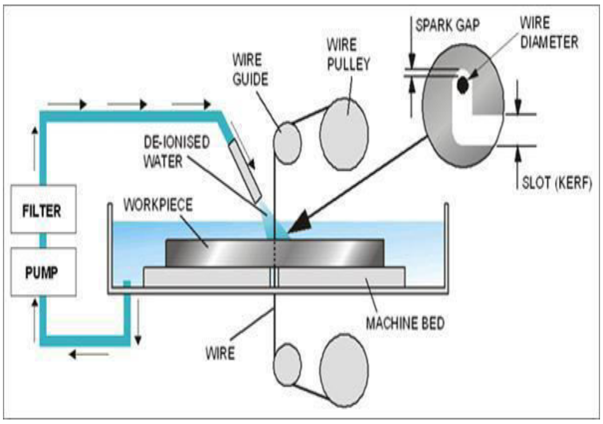

Fig 1.1: Schematic representation of EDM process

The mechanism of metal removal in wire electrical discharge machining mainly involves the removal of material due to melting and vaporization caused by the electric spark discharge generated by a pulsating direct current power supply between the electrodes. In WEDM, negative electrode is a continuously moving wire and the positive electrode is the work piece. The sparks will generate between two closely spaced electrodes under the influence of dielectric liquid. Water is used as dielectric in WEDM, because of its low viscosity and rapid cooling rate.

The applied voltage creates an ionized channel between the nearest points of the work piece and the wire electrodes in the initial stage. In the next stage the actual discharge takes place with heavy flow of current and the resistance of the ionized channel gradually decreases. The high intensity of current continues to further ionize the channel and a powerful magnetic field is generated. This magnetic field compresses the ionized channel and results in localized heating. Even with sparks of very short duration, the temperature of electrodes can locally rise to very high value which is more than the melting point of the work material due to transformation of the kinetic energy of electrons into heat. The high energy density erodes a part of material from both the wire and work piece by locally melting and vaporizing and thus it is the dominant thermal erosion process.

1.2 Applications of WEDM

1. The EDM process is most widely used by the mould-making tool and die industries, but is becoming a common method of making prototype and production parts, especially in the aerospace, automobile and electronics industries

2. It is used to machine extremely hard materials that are difficult to machine like alloys, tool steels, tungsten carbides etc.

3. It is used for forging, extrusion, wire drawing, thread cutting.

4. It is used for drilling of curved holes.

5. It is used for internal thread cutting and helical gear cutting.

7. Higher Tolerance limits can be obtained in WEDM machining. Hence areas that require higher surface accuracy use the WEDM machining process.

8. Ceramic materials that are difficult to machine can be machined by the WEDM machining process.

9. Electric Discharge Machining has also made its presence felt in the new fields such as sports, medical and surgical, instruments, optical, including automotive Research and Development areas.

10. It is a promising technique to meet increasing demands for smaller components usually highly complicated, multi-functional parts used in the field of micro-electronics.

1.3 Advantages of WEDM

1. An important number of CNC features, such as automatic threading of the wire and restarting the operation in the case of wire rupture, improve the performance of WEDM as a manufacturing process.

2. WEDM can machine any complicated profile in electrically conductive materials.

3. Physical and metallurgical properties of the work material, such as strength, hardness, toughness, microstructure, etc. are no barriers to its application.

4. The process generates high surface finish.

5. Complicated contours in hard materials can be produced to a high degree of accuracy and surface finish.

6. It eliminates the geometrical changes occurring in the machining of heat-treated steels.

7. WEDM process simplifies the fabrication of precision work pieces.

8. WEDM produces a sharp, burr-free edge, so it is a highly desirable machining choice for work pieces such as medical implants and die openings.

9. Tool manufacturing and storage is avoided, as the process does not require a special shaped electrode for the purpose of a tool.

10. The time utilization of WEDM is high as it can continuously work throughout the day.

11. Small batch productions including prototypes can be economically machined as most of the CNC programming is easily done.

12. It avoids wastages and rejections due to initial planning and checking of the program.

13. The process can be readily applied to electrically conductive and semi-conductive materials.

14. Although the metal removal is due to thermal effects, there is no heating in the bulk of the material.

15. Heat treatment is usually unnecessary.

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16. During machining, the work piece is not subjected to mechanical deformation as there is no physical contact between the tool and work.

1.4 Limitations of WEDM

1. Its application is limited to small thicknesses and conductive materials.

2. Material removal rate is comparatively low.

3. Electrolysis can occur in some materials.

4. Not suitable for very large work pieces.

5. High capital cost.

6. Precision uniform wire is required

2. INPUT AND OUTPUT PROCESS PARAMETERS

Various parameters affect the efficient working of EDM. Also the appropriate machining strategy can be achieved by proper combination of the parameters. In order to find the feasible procedure for EDM process, there is need to analyze the parameters those influence the process. EDM process is directly influenced by adjustable parameter viz: current, voltage, pulse-on time and pulse-off time, so that the study is concentrated on these only.

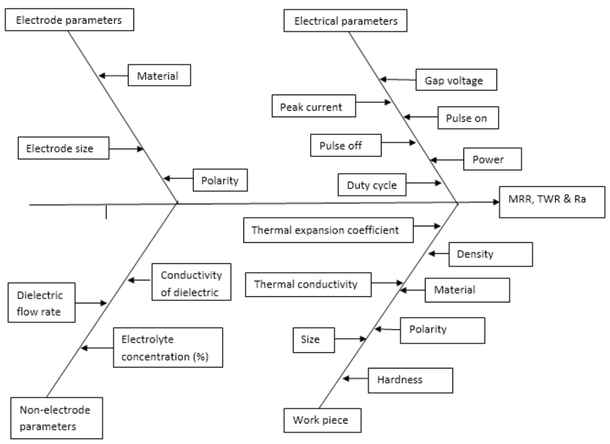

Fig. 2.1: Process parameters of EDM

2.1 Input parameters:

- **Gap voltage (Vg):** It is the amount of potential difference applied in between gap of electrode and work piece, during a particular cycle for a particular period of time. Because of application of voltage electric field is generated in between tool and work piece. It is a potential that can be measure by volt. When the gap voltage (Vg) is increased it increases the material removal rate (MRR) and the surface roughness (R_a) value.
- **Discharge Current (I_P):** It is the value of the current applied to the electrode during pulse on time. Current is measured in Ampere allowed to flow per cycle. It is a measure of the power supplied to the discharge gap. A higher current leads to a higher pulse energy and formation of deeper discharge craters. This increases the material removal rate (MRR) and the surface roughness (R_a) value. Similar effect on MRR and R_a is produced when the gap voltage (Vg) is increased.
- **Pulse on time (Te):** It is the time for which current is applied to the electrode during a particular cycle of EDM. The material removal is directly proportional to the spark energy applied during pulse on time. This energy is controlled by the current and pulse on time. Machining takes place only during the pulse-on time (T_{on}). When the tool electrode is at negative potential, material removal from the anode (work-piece) takes place by bombardment of high energy electrons ejected from the tool surface. At the same time positive ions move towards the cathode. When pulses with small on times are used, material removal by electron bombardment is predominant due to the higher response rate of the less massive electrons. However, when longer pulses are used, energy sharing by the positive ions is predominant and the material removal rate decreases. When the electrode polarities are reversed, longer pulses are found to produce higher MRR.
- **Pulse off time (T_{off}):** The duration of time (µs) between the sparks. A non-zero pulse off time is a necessary requirement for EDM operation. Discharge between the electrodes leads to ionization of the spark gap. Before another spark can take place, the medium must de-ionize and regain its dielectric strength. This takes some finite time and power must be switched off during this time. Too low values of pulse-off time may lead to short-circuits and arcing. A large value on the other hand increases the overall machining time since no machining can take place during the off-time. It is the time for which voltage is retracted during a particular cycle. Melted and solidified particles are removed from the gap during this period.

2.2 Output parameters:

The machining performance of the WEDM process can be evaluated by the material removal rate and surface roughness. The accuracy of the holes can be evaluated by surface roughness.

- **Material Removal Rate:**

The MRR for each run is to be calculated by weight difference of specimen before and after the machining of each hole.

$$MRR=\frac{W_1-W_2}{T_m}\ \text{gm/min}$$

Where, W1= weight of specimen before machining

W2= weight of specimen after machining

Tm= machining time

- **Surface Roughness**

The average roughness (R_a) is the area between the roughness profile and its mean line, or the integral of the absolute value of the roughness profile height over the evaluation length. There are many methods of measuring surface roughness, such as image processing microscopes, stylus type instruments, and profile tracing instruments.

METHODOLOGY

Design of Experiment by

1. Response Surface Methodolgy
2. Taguchi's orthogonal array

Mathematical Analysis by

1. Regression analysis

Optimization of Process Parameter by

1. Gray relational analysis

3. DESIGN OF EXPERIMENT

Design of Experiment (DOE) is an efficient experiment planning process that allows the data obtained to be analyzed, valid conclusions to be drawn and objectives to be set. There are two aspects of any experimental problem, the design of experiment and statistical analysis. Experimental design involves planning experiments to obtain the maximum amount of information from available resources.

DOE is used to determine the appropriate number of tests and the experimental conditions necessary to obtain the desired goal of analyzing which factor of the process influences the response variables. The most common design consists of running the test with all the possible combinations of variables at predetermined levels.

A well-planned design of experiment can substantially reduce the number of experiments and for this reason a small CCD with five levels was selected to develop the first order and second order models. In the present investigation, experiments were performed on the basis of the Design of Experiments (DOE) technique. The design chosen was full factorial design 2^3 with 8 cube point,4 center point in cube,6 axial point and 2 center point in axial.

Response surface methodology (RSM) is a collection of mathematical and statistical methods to evaluate relationships between a group of quantitative independent variables and one or more responses. The RSM enables to evaluate operation variables that may or may not have significant effect in the main response. The central composite design, CCD, is used to build a second order experimental model. CCD is composed of a factorial design, a set of central points, and axial points equidistant to the center point.

The factorial design component of CCD is of the class 2*k* factorial where *k* represents the number of relevant factors or variables. Each of the variables is taken at two levels meaning that each variable has a low and high numeric value. A coded numeric value of -1 and +1 is assigned to represent the variable's low and high values. The geometric representation of a factorial is a cube in which each corner represents an interaction of the factors. In this perspective, 3 processing variables are selected to determine their significance in the final response.

The axial component of CCD refers to the points that are equidistant from the center of the cube formed for the factorial design. A spherical design is obtained in the reason that there is an equal variance from the center to all the points in the sphere. In consequence, there is a positive axial value (+a) and a negative axial value (-a). The axial points add two more levels in each variable. The a value is calculated from the equation a = (ni)1/4. Where, ni represent the number of interactions obtained from the factorial design. The central point component in the CCD is the average of the high and low values determined in the factorial design. The central point or zero point may be defined as the region where the optimal conditions are supposedly met. The purpose of adding center points:

- To provide a measure of process stability and inherent variability.
- To check for curvature.

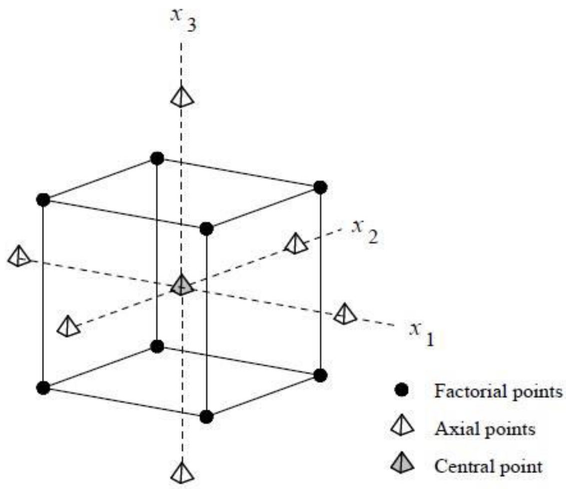

Fig 3.1: CCD showing 8 factorial points, 6 axial points and 6 center points used for experimentation.

The RMS allows the introduction of blocks that facilitate the accomplishment of experiments. Blocking is justified based on the physical and time limitations to run experiments. However, blocking may have some effects over the final response. If the estimations of the independent and interaction effects of the selected variables are not affected by blocking, the inclusion of blocks in the experimental design is justified. The selection of variables for the analysis using RSM is completed in order to determine which factor may or may not have an important effect in the final response.

3.1 Selected input and output process parameters:

In electrical discharge machining there are lot many process parameters which affects machining like dielectric medium, tool material, supply voltage, electrode type, inter electrode gap, surface roughness of tool material, duty factor etc. Considering the study of previous researchers in the field of micro EDM which are mentioned in literature survey, following input process parameters are selected to carry out the experiments.

Input process parameters:

1. Current
2. Voltage
3. Pulse-on time

Output process parameters:

1. Material removal rate
2. Tool wear rate
3. Surface roughness

4.CONCLUSION

In this work, experimental investigation will be reported for Wire Electric Discharge Machining on D2 tool steel. An overview of the principle of WEDM, its Experimental set-up and machining process is discussed. The report focuses on problem related to Wire Electric Discharge machining to improve MRR and to reduce surface roughness (R_a). Optimization will be carried out, for stable machining condition.

- ❑ Significant parameters affecting the machining performance will be determined through experiments.
- ❑ Effect of current, voltage and pulse on time will be studied on material removal rate and surface roughness.
- ❑ Mathematical models will be established relating the input parameters to the responses by regression analysis.
- ❑ Optimal parameters setting will be obtained so that the machine can work consistently for a longer duration.

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