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EFFECT OF PROCESS PARAMETERS ON PERFORMANCE MEASUREMENT OF WIRE ELECTRICAL DISCHARGE MACHINING

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ABSTRACT: 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 or impossible to cut with traditional methods. The machines also specialize in cutting complex contours or fragile geometries that would be difficult to be produced using conventional cutting methods. Machine tool industry has made exponential growth in its manufacturing capabilities in last decade but still machine tools are not utilized at their full potential. This limitation is a result of the failure to run the machine tools at their optimum operating conditions. The problem of arriving at the optimum levels of the operating parameters has attracted the attention of the researchers and practicing engineers for a very long time.

[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. 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.

IMPORTANCE OF WEDM PROCESS IN PRESENT DAY MANUFACTURING

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 (Ho et. al., 2004). 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 (Kozak et.al., 2004 and Lok and Lee, 1997). 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

[2] Literature review

Huang et al. (2003)

reported the microstructure analysis for martensitic stainless steel quenched and then tempered at 600°C. Specimens of the material were finished with either 4 or 5 cutting passes. Negatively polarized wire electrode (NPWE) was applied in the first four cutting passes, except the last cutting pass, in which the positively polarized wire electrode (PPWE) was used. From the results of scanning electron microscopy (SEM) examination, craters and martensitic grains were registered in the micrograph of the finished surface machined after the 4th cutting pass. From the results of transmission electron microscopes TEM-examination, a heat-affected zone (HAZ) of 1.5μm thick was detected in the surface layer finished with NPWE.

Gauri and Chakraborty (2008)

suggested a modified approach of the principal component analysis (PCA) based procedure for multi-response optimization. Analysis was done data on experimental data on WEDM processes obtained by the past researchers i.e. on γ-titanium aluminized alloy with the settings of six controllable factors. Quality characteristics were material removal rate (MRR) (larger the better type), surface roughness (SR) (smaller the better type) and wire wear ratio (WWR) (smaller the better type).

Ramakrishnan and Karunamoorthy (2008)

developed artificial neural network (ANN) models and multi response optimization technique to predict and select the best cutting parameters of wire electro-discharge machining (WEDM) process. Inconel 718 was selected as work material to conduct experiments and brass wire of 0.25mm diameter was used as tool electrode. Experiments were planned as per Taguchi‟s L-9 orthogonal array. Experiments were performed under different cutting conditions of pulse on time, delay time, wire feed speed and ignition current. It was found that the pulse on time, delay time and ignition current had more influence than wire feed speed on the performance characteristics considered in the study. An MRR was improved with increase in pulse on time and ignition current. But the surface quality of the work specimen was affected adversely with increased value of pulse on time and ignition current.

Kanlayasiri and Boonmung (2007)

investigated influences of wire-EDM machining variables on surface roughness of newly developed DC 53 die steel of width, length, and thickness 27, 65 and 13 mm, respectively. The machining variables included pulse-on time, pulse-off time, pulse-peak current, and wire tension. The variables affecting the surface roughness were identified using ANOVA technique. Results showed that pulse on time and pulse-peak current were significant variables to the surface roughness of wire EDMed DC53 die steel. The maximum prediction error of the model was less than 7% and the average percentage error of prediction was less than 3%.

[3] Taguchi's Philosophy

Taguchi‟s comprehensive system of quality engineering is one of the greatest engineering achievements of the 20th century. His methods focus on the effective application of engineering strategies rather than advanced statistical techniques. It includes both upstream and shop-floor quality engineering. Upstream methods efficiently 44 use small-scale experiments to reduce variability and remain cost-effective, and robust designs for large-scale production and market place. Shop-floor techniques provide cost based, real time methods for monitoring and maintaining quality in production. The farther upstream a quality method is applied, the greater leverages it produces on the improvement, and the more it reduces the cost and time. Taguchi‟s philosophy is founded on the following three very simple and fundamental concepts (Ross, 1988; Roy,

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1990):

• Quality should be designed into the product and not inspected into it.

• Quality is best achieved by minimizing the deviations from the target. the product or process should be so designed that it is immune to uncontrollable environmental variables.

• The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system-wide.

Taguchi proposes an "off-line" strategy for quality improvement as an alternative to an attempt to inspect quality into a product on the production line. He observes that poor quality cannot be improved by the process of inspection, screening and salvaging. No amount of inspection can put quality back into the product. Taguchi recommends a three-stage process: system design, parameter design and tolerance design (Ross, 1988, Roy, 1990). In the present work Taguchi"s parameter design approach is used to study the effect of process parameters on the various responses of the WEDM process.

Experimental Design Strategy

Taguchi recommends orthogonal array (OA) for laying out of experiments. These OA"s are generalized Graeco-Latin squares. To design an experiment is to select the most suitable OA and to assign the parameters and interactions of interest to the appropriate columns. The use of linear graphs and triangular tables suggested by Taguchi makes the assignment of parameters simple. The array forces all experimenters to design almost identical experiments (Roy, 1990). In the Taguchi method the results of the experiments are analyzed to achieve one or more of the following objectives (Ross, 1988): To establish the best or the optimum condition for a product or process• To estimate the contribution of individual parameters and interactions• 45 To estimate the response under the optimum condition• The optimum condition is identified by studying the main effects of each of the parameters. The main effects indicate the general trends of influence of each parameter. The knowledge of contribution of individual parameters is a key in deciding the nature of control to be established on a production process. The analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiments in determining the percent contribution of each parameter against a stated level of confidence. Study of ANOVA table for a given analysis helps to determine which of the parameters need control (Ross, 1988). Taguchi suggests (Roy, 1990) two different routes to carry out the complete analysis. First, the standard approach, where the results of a single run or the average of repetitive runs are processed through main effect and ANOVA analysis (Raw data analysis). The second approach which Taguchi strongly recommends for multiple runs is to use signal- to-noise ratio (S/N) for the same steps in the analysis. The S/N ratio is a concurrent quality metric linked to the loss function (Barker, 1990). By maximizing the S/N ratio, the loss associated can be minimized. The S/N ratio determines the most robust set of operating conditions from variation within the results. The S/N ratio is treated as a response (transform of raw data) of the experiment. Taguchi recommends (Ross, 1988) the use of outer OA to force the noise variation into the experiment i.e. the noise is intentionally introduced into experiment. However, processes are often times subject to many noise factors that in combination, strongly influence the variation of the response. For extremely „noisy" systems, it is not generally necessary to identify specific noise factors and to deliberately control them during experimentation. It is sufficient to generate repetitions at each experimental condition of the controllable parameters and analyze them using an appropriate S/N ratio (Byrne and Taguchi, 1987). In the present investigation, the raw data analysis and S/N data analysis have been performed. The effects of the selected WEDM process parameters on the selected quality characteristics have been investigated through the plots of the main effects based on raw data. The optimum condition for each of the quality characteristics has been established 46 through S/N data analysis aided by the raw data analysis. No outer array has been used and instead, experiments have been repeated three times at each experimental condition.

SELECTION OF PROCESS PARAMETERS

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In order to identify the process parameters that may affect the machining characteristics of WEDM machined parts an Ishikawa cause and effect diagram was constructed and is shown in Figure

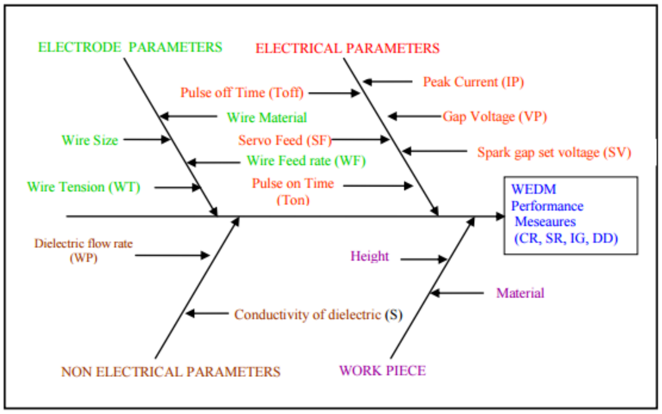

Fig:1 Ishikawa cause and effect diagram for WEDM Process.

The input process parameters and output characteristics selected from Ishikawa cause and effect diagram for the present work are shown in Figure

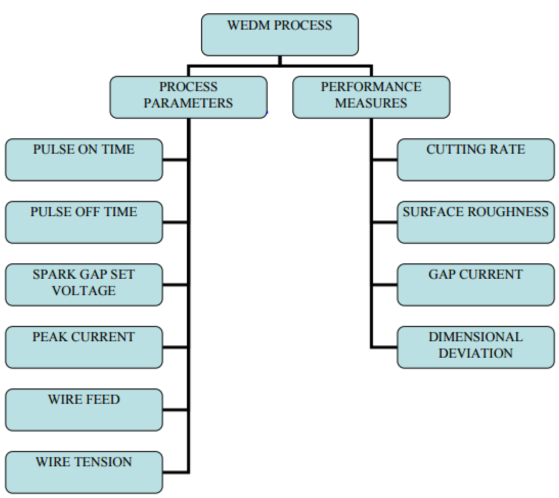

Fig: 2 Process Parameters and Performance Measure of WEDM

Pulse on Time

The pulse on time is referred as Ton and it represents the duration of time in micro seconds, μs, for which the current is flowing in each cycle. During this time the voltage, VP, is applied across the electrodes. The Ton setting time range available on the machine tool is 100-131 which is applied in steps of 1 unit. The single pulse discharge energy increases with increasing Ton period, resulting in higher cutting rate. With higher values of Ton, however, surface roughness tends to be higher. The higher value of discharge energy may also cause wire breakage.

Pulse off Time

The pulse off time is referred as Toff and it represents the duration of time in micro seconds, μs, between the two simultaneous sparks The voltage is absent during this part of the cycle. The Toff setting time range available on the machine tool is 00 - 63 which is applied in steps of 1 unit. With a lower value of Toff, there are more number of discharges in a given time, resulting in increase in the sparking efficiency. As a result, the cutting rate also increases. Using very low values of Toff period, however, may cause wire breakage which in turn reduces the cutting efficiency. As and when the discharge conditions become unstable, one can increase the Toff period. This will allow lower pulse duty factor and will reduce the average gap current.

Servo Voltage

Servo voltage acts as the reference voltage to control the wire advances and retracts. If the mean machining voltage is higher than the set servo voltage level, the wire advances, and if it is lower, the wire retracts. When a smaller value is set, the mean gap becomes narrower, which leads to an increase in number of electric sparks, resulting in higher machining rate. However, the state of machining at the gap may become unstable, causing wire breakage.

Peak Current

Peak current is the amount of power used in discharge machining and is measured in unit of amperage. The current increases until it reaches a preset value during each pulse on time, which is known as peak current, is shown in figure 2. Peak current is governed by surface area of cut. Higher peak current is applied during roughing operation and details with large surface area. Shows peak current, pulse-off time and on time

Gap Voltage

Gap voltage, also called open circuit voltage specifies the supply voltage to be placed on the gap. Greater the gap voltage, greater will be the electric discharge. If the gap voltage increases, the peak current will also increase. In some WEDM machines both of these factors show machining voltage.

Dielectric flow rate

Dielectric flow rate is the rate at which the dielectric fluid is circulated. Flushing is important for efficient machining. Flushing pressure is produced from both the top and bottom nozzles.

Wire Feed rate

As the wire feed rate increases, the consumption of wire as well as cost of machining will increase. Low wire speed will cause wire breakage in high cutting speed.

Wire Tension

If the wire tension is high enough the wire stays straight otherwise wire drags behind. Within considerable range, an increase in wire tension significantly increases the cutting speed and accuracy. The higher tension decreases the wire vibration amplitude and hence decreases the cut width so that the speed is higher for the same discharge energy. However, if the applied tension exceeds the tensile strength of the wire, it leads to wire breakage.

SELECTION OF RANGE OF PARAMETERS

Ranges of the process parameters, different levels of process parameters would be selected for Taguchi experimental design and experimental design methodology using response surface methodology.

Table: 1 Process Parameters, Symbols and their range

Process Parameters	Symbol	units	Range (machine units)	Range (actual units)
Pulse on Time	Ton	µs	105-126	0.35-1.4 µs
Pulse off time	Toff	µs	40-63	14 -52 µs
Spark gap set voltage	SV	V	10-50	10-50 volt
Peak Current	IP	A	70-230	70-230 ampere
Wire Feed	WF	m/min	4-12	4 -12 m/min
Wire Tension	WT	gram	4-12	500-1800 gram

Selection of orthogonal array (OA)

In selecting an appropriate OA, the pre-requisites are (Ross, 1988; Roy, 1990):

•Selection of process parameters and/or interactions to be evaluated

• Selection of number of levels for the selected parameter

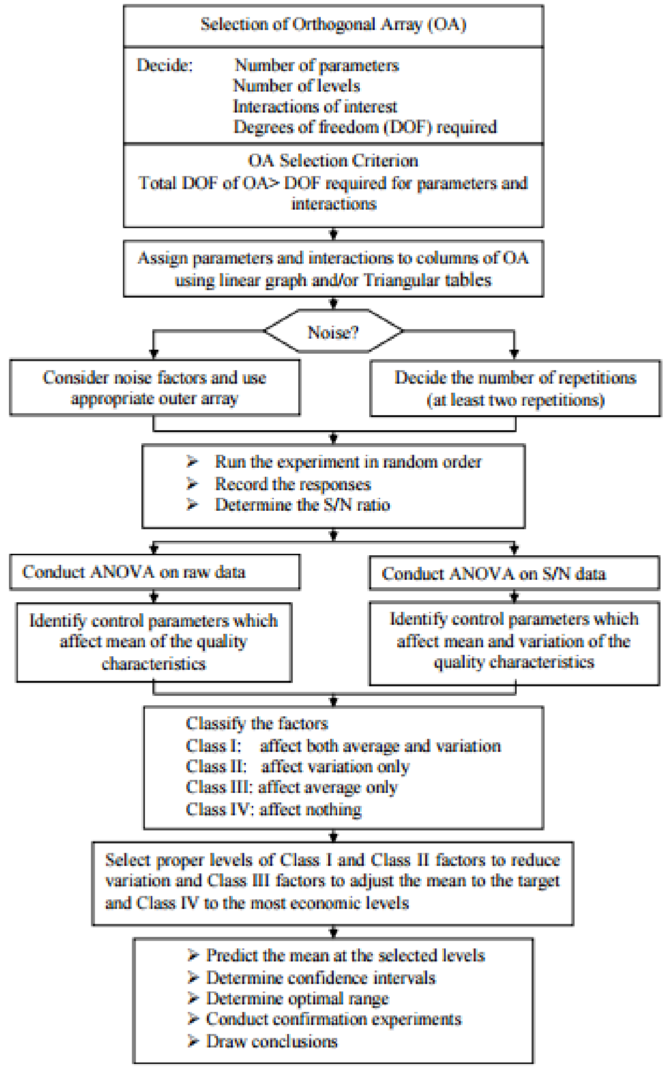

Fig:3 Taguchi Experimental Design and Analysis Flow Diagram

Assignment of parameters and interaction to the OA

The OA"s have several columns available for assignment of parameters and some columns subsequently can estimate the effect of interactions of these parameters. Taguchi has provided two tools to aid in the assignment of parameters and interactions to arrays (Ross, 1988; Roy, 1990):

1. Linear graphs

2. Triangular tables

Each OA has a particular set of linear graphs and a triangular table associated with it. The linear graphs indicate various columns to which parameters may be assigned and the columns subsequently evaluate the interaction of these parameters. The triangular tables contain all the possible interactions between parameters (columns). Using the linear graphs and /or the

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triangular table of the selected OA, the parameters and interactions are assigned to the columns of the OA.

Selection of outer array

Taguchi recommends the use of outer array for the noise factors and inner arrays for controllable factors. If an outer array is used, the noise variation is forced into the experiment. However, experiments against the trial conditions of the inner array (the OA used for the controllable factors) may be repeated and in this case the noise variation is unforced into the experiment (Byrne and Taguchi, 1987). The outer array, if used, will have same assignment considerations.

[4] RESPONSE SURFACE METHODOLOGY

Response surface methodology (RSM) is a collection of mathematical and statistical techniques useful for analyzing problems in which several independent variables influence a dependent variable or response, and the goal is to optimize this response (Cochran and Cox, 1962). In many experimental conditions, it is possible to represent independent factors in quantitative form as given in Equation 4.12. Then these factors can be thought of as having a functional relationship with response as follows:

$$Y=\phi(x_1, x_2, \ldots\ldots, x_k) \pm e_r$$

Analysis of Variance

For the analysis of variance, the total sum of squares may be divided into four parts:

- The contribution due to the first order terms
- The contribution due to the second order terms
- A „Lack of fit" component which measures the deviations of the response from
- the fitted surface Experimental error which is obtained from the centre points

[6] Conclusion

The effects of process variables on response characteristics (cutting rate, surface roughness, gap current and dimensional deviation) of the wire electric discharge machining (WEDM) process have been discussed. An optimal set of process variables that yields the optimum quality features to machined parts produced by WEDM process has also been obtained. The important conclusions from the present research work are summarized

1. Ranges of Wire EDM process parameters have been established based on review of literature and by performing the pilot experiments using one factor at a time (OFAT) approach.

2. The effects of the process parameters viz. pulse on time, pulse off time, spark gap set voltage, peak current, wire tension and wire feed, on response characteristics viz. cutting rate, surface roughness, gap current and dimensional deviation, were studied.

3. The optimal sets of process parameters were obtained for various performance measures using Taguchi"s design of experiment methodology. The summary results of predicted 249 optimal values of the responses and their confidence intervals (both for confirmation experiment and population) are given

4. Response surface methodology (RSM) was applied for developing the mathematical models in the form of multiple regression equations correlating the dependent parameters with the independent parameters (pulse on time, pulse off time, spark gap set voltage, peak current, wire tension) in WEDM machining of H-11 steel.

5 Desirability function in combination with response surface methodology has been used for single response optimization. Optimal sets of process parameters, predicted optimal response and desirability value for single response optimization are summarized

6. Concept of desirability in combination with RSM has also been used for simultaneous optimization of response characteristics of conflicting nature. The optimal sets of process parameters for multi response optimization with maximum desirability of the selected performance measures were found as per the assumed models. The optimal values of process parameters for multi response optimization using RSM and desirability function are reported

7. The Utility concept has been used along with Taguchi technique for multi-response optimization. In the multi-response problem, various combinations of responses were studied. The optimal sets of process parameters for multi

response optimization using Taguchi"s technique and utility concept are reported

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