An Experimental Analysis of Optimization of Process Parameters on Performance Measure of WEDM of SS304

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ABSTRACT

In this paper the author has described an experimental analysis of optimization of process parameters on performance measure of WEDM of SS304With the increasing demands of high surface finish and machining of complex shape geometries, conventional machining process are now being replaced by non-traditional machining processes. Wire electrical discharge machining (WEDM) allowed success in the production of newer materials, especially for the aerospace and medical industries. Using WEDM technology, complicated cuts can be made through difficult-to-machine electrically conductive components. The high degree of the obtainable accuracy and the fine surface quality make WEDM valuable. WEDM is so complex in nature that the selection of appropriate input parameters is not possible by the trial-and-error method. The selection of machining parameters in any machining process significantly affects production rate, product quality and production cost of a finished component. WEDM process involves a large number of variables that affect its performance. Wire EDM is one of the non-traditional machining processes. Surface roughness and MRR are of crucial importance in the field of machining processes. The objective of optimization is to attain the maximum MRR and the best surface quality simultaneously and separately. In this present study stainless steel 304 is used as a work piece, brass wire of 0.25mm diameter used as a tool and distilled water is used as dielectric fluid. For experimentation Taguchi's, L9 orthogonal array has been used. The input parameters selected for optimization are wire tension, wire feed, pulse on time, and pulse off time. Also the effects of the input process parameters over the MRR and Ra were plotted and studied. Later the developed models can be utilized for optimization.

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1. INTRODUCTION

WEDM process is one of the most widely used non-traditional machining processes in current manufacturing. It involves the removal of metal by discharging an electrical current from a pulsating DC power supply across a thin inter-electrode gap between the tool and the work piece. It is most commonly used for machining hard and difficult to machine materials with very close tolerances. Generally, WEDM is perceived to be an extremely actuate process and there are various reasons for this perception.

It can machine anything that is electrically conductive regardless of the hardness, from relatively common materials such as tool steel, aluminum, copper, and graphite, to exotic space-age alloys including hastaloy, waspaloy, inconel, titanium, carbide, polycrystalline diamond compacts and conductive ceramics. The wire does not touch the workpiece, so there is no physical pressure imparted on the workpiece compared to grinding wheels and milling cutters. The amount of clamping pressure required to hold small, thin and fragile parts is minimal, preventing damage or distortion to the workpiece.

Wire EDM also gives designers more latitude in designing dies, and management more control of manufacturing, since the machining is completed automatically. Parts that have complex geometry and tolerances don't require you to rely on different skill levels or multiple equipment. Substantial increases in productivity is achieved since the machining is untended, allowing operators to do work in other areas. Most machines run overnight in a "lights-out" environment. Long jobs are cut overnight, or over the weekend, while shorter jobs are scheduled during the day. Most workpieces come off the machine as a finished part, without the need for secondary operations. It's a one-step process.

Importance of Wire Electric Discharge Machining in 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). 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.

Working Principle of WEDM

The mechanism of material removal in WEDM is similar to conventional machining process in which erosion effect produced by the series of electrical sparks produced between the work piece & the wire electrode surrounded by stream of dielectric fluid continuously flowing in the machining Zone. A temperature range of 8000°C–12,000°C exist between cathode and anode in the form of thermal energy after applying voltage pulses between the work–piece and the wire electrode during WEDM process. When the pulsating DC power supply occurring between 20,000 and 30,000 Hz is turned off, the plasma channels breaks down.

A series of electrical pulses generated by the pulse generator unit is applied between the work piece and the travelling wire electrode, to cause the electro erosion of the workpiece material. As the process proceeds, the X-Y controller displaces the worktable carrying the workpiece transversely along a predetermined path programmed in the controller. While the machining operation is continuous, the machining zone is continuously flushed with water passing through the nozzle on both sides of work piece. Since water is used as a dielectric medium, it is very important that water does not ionize. Therefore, in order to prevent the ionization of water, an ion exchange resin is used in the dielectric distribution system to maintain the conductivity of water.In order to produce taper machining, the wire electrode has to be tilted. This is achieved by displacing the upper wire guide (along U-V axis) with respect to the lower wire guide. The desired taper angle is achieved by simultaneous control of the movement of X-Y table and U-V table along their respective predetermined paths stored in the controller. The path information of X-Y table and U-V table is given to the controller in terms of linear and circular elements via NC program. Figure 1 exhibits the schematic diagram of the basic principle of WEDM process (Saha et. al., 2004)[3].
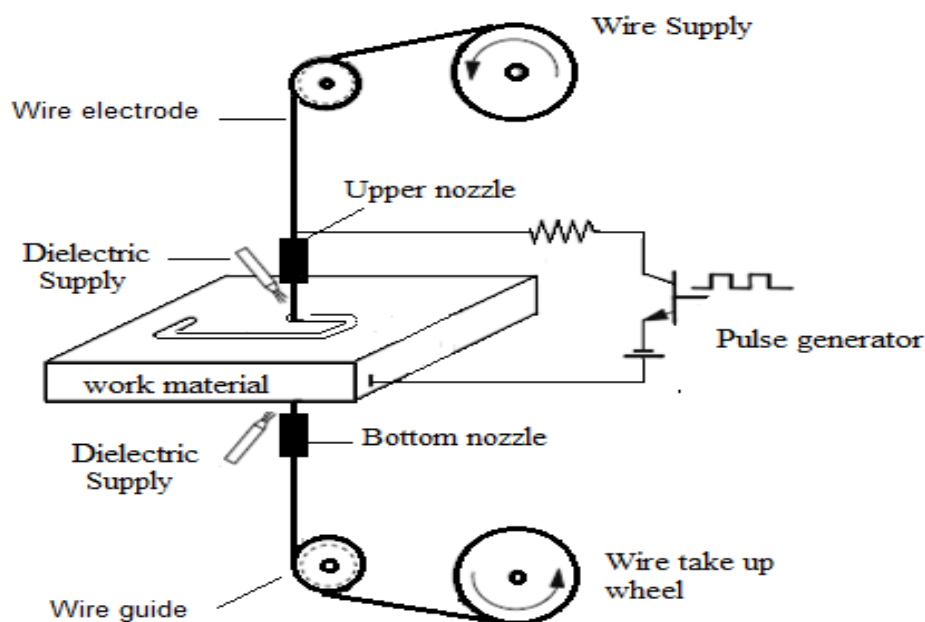

Fig 1 : Schematic Representation Of WEDM Process

2. LITERATURE REVIEW

A number of research papers exist in the literature related to these newly developed optimization techniques. Many researchers used the concept of genetic algorithms for solving the complex formulated problems of the wire Electric Discharge Machining process. The stress has been given on understanding the problem from the core and some of the research papers used for formulation and understanding the problem are outlined as below:

Williams and rajurkar (1991) performed experimental investigations on WEDM to study the wire electrical discharged machined surface characteristics. The objective of research was to stochastically model and analyze WEDM surface profiles to gain a better understanding of the surface generating mechanism. Further scanning electron microscopy and energy dispersive spectrometry were also used to study WEDM surface characteristics.

 Lin and Lin (2001) reported a new approach for the optimization of the electrical discharge machining (EDM) process with multiple performance characteristics based on the orthogonal array with the grey relational analysis. Optical machining parameters were determined by the grey relational grade obtain from the grey relational analysis as the performance index. The machining parameters, namely work piece, polarity, pulse on time, duty factor, open discharge voltage, discharge current and dielectric fluid were optimized with considerations of multiple performance characteristics including material removal rate, surface roughness, and electrode wear ratio.

Puri and Bhattachryya (2003) employed Taguchi methodology involving thirteen control factors with three levels for an orthogonal array L27 to find out the main parameters that affects the different machining criteria, such as average cutting speed, surface roughness values and the geometrical inaccuracy caused due to wire lag.

Huang and liao (2003) presented the use of grey relational and S/N ratio analysis, for determining the optimal parameters setting of WEDM process. The results showed that the MRR and surface roughness are easily influenced by the table feed rate and pulse on time.

Kuriakose et al .(2004) carried out experiments with titanium alloy (Ti-6Al-4V) and used a data- mining technique to study the effect of various input parameters of WEDM process on the cutting speed and SR. They reformulated the WEDM domain as a classification problem to identify the important decision parameters. In their approach, however, the optimal process parameters for the multiple responses need to be decided by the engineers based on judgment.

Yan et al. (2005) performed experiments on FANUC WI CNC wire electrical discharge machine for cutting both the 10 and 20 vol. % AL203 particles reinforced 6061 Al alloys-based composite and 6061 Al matrix material itself. Results indicated that the cutting speed (material removal rate), the surface roughness and the width of the slit of cutting test material significantly depend on volume fraction of reinforcement (Al203 particles).

Sarkar et al. (2005) perform experimental study using ɤ-titanium aluminide alloy as work material and then formulation of mathematical models to predict the cutting speed, surface finish and dimensional deviation as the function of different control parameters. They determined the optimal process parameters by applying constrained optimization technique in which one performance characteristics was optimized considering other as constraints.

Kuriakose and shunmugam (2005)used titanium alloy (Ti-6Al-4V) as the work material and conducted experiments based on taguchi''s L-18 orthogonal array. Then they employed the non-dominated sorting genetic algorithm to determine the optimal process parameters that would optimize cutting velocity and SR of WEDM process.

Ramakrishnan and karunamoorthy (2006) performed the multi objective optimization of the WEDM process using parametric design of Taguchi methodology. The effect of various machining parameters such as pulse on time, wire feed speed, wire tension, delay time, and ignition current intensity has been studied in machining of heat-treated tool steel. It was identify that the pulse on time and ignition current intensity has influence more than the other parameters. Moreover, the multiple performance characteristics such as material removal rate, surface roughness, and wire wear ratio for the WEDM process could be improved by setting the various process parameters at their various levels.

3. TAGUCHI'S EXPERIMENTAL DESIGN & METHODOLOGY

3.1 Taguchi's Philosophy

Dr. Genichi Taguchi is regarded as the foremost proponent of robust parameter deign, which is an engineering method for product or process design that focuses on minimizing variation and/or sensitivity to noise. When used properly, Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. Taguchi proposed several approaches to experimental designs that are sometimes called "Taguchi Methods." These methods utilize two-, three-, four-, five-, and mixed-level fractional factorial designs.

Taguchi refers to experimental design as "off-line quality control" because it is a method of ensuring good performance in the design stage of products or processes.

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 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. 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 of 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 measure 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. 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. Loss Function and S/N Ratio The heart of Taguchi method is his definition of the nebulous and elusive term "quality" as the characteristic that avoids loss to the society from the time the product is shipped. Loss is measured in terms of monetary units. Taguchi defines quality loss via his "loss function". He unites the financial loss with the functional specification through a quadratic relationship that comes from a Taylor series expansion. The quadratic function takes the form of a parabola. Taguchi defines the loss function as a quantity proportional to the deviation from the nominal quality characteristic. He has found the following quadratic form to be a useful workable function:

$$L(y) = k(y-m)^2$$

Where, L = Loss in monetary units

m = value at which the characteristic should be set

y = actual value of the characteristic

k = constant depending on the magnitude of the characteristic and the

Monetary unit involved.

The characteristics of the loss function are:

- The farther the product's characteristic varies from the target value, the greater is the loss. The loss must be zero when the quality characteristic of a product meets its target value.

- The loss is a continuous function and not a sudden step as in the case of traditional (goal post) approach. This consequence of the continuous loss function illustrates the point that merely making a product within the specification limits does not necessarily mean that product is of good quality.

Signal to Noise Ratio

The loss-function discussed above is an effective figure of merit for making engineering design decisions. However, to establish an appropriate loss-function with its

- Taguchi Loss Function
- Traditional (Goal-Post) Approach

The S/N ratio, as stated earlier, is a concurrent statistic. A concurrent statistic is able to look at two characteristics of a distribution and roll these characteristics into a single number or figure of merit. The S/N ratio combines both the parameters (the mean level of the quality characteristic and variance around this mean) into a single metric. A high value of S/N implies that signal is much higher than the random effects of noise factors. Process operation consistent with highest S/N always yields optimum quality with minimum variation.

The mean squared deviation (MSD) is a statistical quantity that reflects the deviation from the target value. The expressions for MSD are different for different quality characteristics. For the "nominal is best" characteristic, the standard definition of MSD is used. For the other two characteristics the definition is slightly modified. For "smaller is better", the unstated target value is zero. For "larger is better", the inverse of each large value becomes a small value and again, the unstated target value is zero. Thus for all three expressions, the smallest magnitude of MSD is being sought.

3.2 Selection of Orthogonal Array (OA)

Table 1: Standard orthogonal arrays

Orthogonal array	Number of rows	Maximum number of Factors	Maximum number of columns at these levels			
			2	3	4	5
L_4	4	3	3	-	-	-
L_8	8	7	7	-	-	-
L_9	9	4	-	4	-	-
L_{12}	12	11	11	-	-	-
L_{16}	16	15	15	-	-	-
L_{18}	16	5	-	-	5	-
L_{18}	18	8	1	7	-	-
L_{25}	25	6	-	-	-	6
L_{27}	27	13	-	13	-	-
L_{32}	32	31	31	-	-	-
L_{32}	32	10	1	-	9	-
L_{36}	36	23	11	12	-	-
L_{36}	36	16	3	13	-	-
L_{50}	50	12	1	-	-	11
L_{54}	54	26	1	25	-	-
L_{64}	64	63	63	-	-	-
L_{64}	64	21	-	-	21	-
L_{81}	81	40	-	40	-	-

In selecting an appropriate OA, the pre-requisites are:

- Selection of process parameters and/or interactions to be evaluated
- Selection of number of levels for the selected parameters

The determination of which parameters to investigate hinges upon the product or process performance characteristics or responses of interest. Several methods are suggested by Taguchi for determining which parameters to include in an experiment.

These are:

a) Brainstorming b) Flow charting c) Cause-Effect diagrams

The total Degrees of Freedom (DOF) of an experiment is a direct function to total number of trials. If the number of levels of a parameter increases, the DOF of the parameter also increases because the DOF of a parameter is the number of levels minus one. Thus, increasing the number of levels for a parameter increases the total degrees of freedom in the experiment which in turn increases the total number of trials. Thus, two levels for each parameter are recommended to minimize the size of the experiment. If curved or higher order polynomial relationship between the parameters under study and the response is expected, at least three levels for each parameter should be considered.

The standard three levels OA is L9 array. The number as subscript in the array designation indicates the number of trials in that array. The total degrees of freedom (DOF) available in an OA are equal to the number of trials minus one. Depending on the number of levels of the parameters and total DOF required for the experiment, a suitable OA is selected.

4. EXPERIMENTAL ANALYSIS

Machine Tool

The experiments were carried out on a wire-cut EDM machine (ELEKTRA SPRINTCUT 734) of Electronica Machine Tools Ltd.

Fig. 2: WEDM Machine Tool

The WEDM machine tool (Fig. 2) has the following specifications:

Table 2: Specification of Machine

Design	: Fixed column, moving table
Table size	: 440 x 650 mm
Max. workpiece height	: 200 mm
Max. workpiece weight	: 500 kg
Main table traverse (X, Y)	: 300, 400 mm
Auxiliary table traverse (u, v)	: 80, 80 mm
Wire electrode diameter	: 0.25 mm (Standard)
Generator	: ELPULS-40 A DLX
Controlled axes	: X Y, U, V simultaneous / independent
Interpolation	: Linear & Circular
Least input increment	: 0.0001mm
Least command input (X, Y, u, v)	: 0.0005mm
Input Power supply	: 3 phase, AC 415 V, 50 Hz
Connected load	: 10 KVA
Average power consumption	: 6 to 7 KVA

The stainless steel 304 plate of size 243mm×75mm×4mm has been used as a workpiece material for the present experiment. SS 304 provides the better corrosion resistance well as higher strength at elevated temperatures than SS 304. It is often used for pumps, valves, chemical equipment's and marine applications. It is most popular of stainless steels.

CONCLUSIONS

The proposed experimental work on WEDM of Stainless Steel (SS 304) is performed with a view to correlate the process parameters viz. Pulse on time (T_{ON}), Pulse off time (T_{OFF}), Wire feed (WF), Wire tension (WT) with the performance measures of Material removal rate (MRR) and Surface roughness (Ra). The process has been successfully modelled by using Taguchi's design of methodology and analysis is carried out by using Minitab 16 software. Finally, an attempt has been made to estimate the optimum machining conditions to produce the best possible response within the experimental constraints. The following conclusions have been made on the basis of present investigation.

- The present investigation develops a model for four factors (Pulse on time, Pulse off time, Wire feed and Wire tension) and three levels on Stainless steel 304 (SS304).
- The optimum parameters for Material Removal Rate (MRR) are as follows: Pulse on time = 117μs, Pulse off time = 57 μs, Wire feed = 5 m/min, Wire tension = 9 grams.
- The optimum parameters for Surface Roughness (Ra) are as follows: Pulse on time = 115μs, Pulse off time = 55 μs, Wire feed = 5 m/min, Wire tension = 9 grams.
- The order strength parameters are found from response table for MRR is T_{on}, T_{off}, Wire feed and Wire tension.
- The order strength parameters are found from response table for Surface Roughness is Wire feed, T_{on}, T_{off} and wire tension.
- After performing the experiments it is concluded that with the increase in Pulse on time the MRR in the present work increase for SS 304.

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