A study on Addendum length of a micro gear in wire electrical discharge machining based on Taguchi method

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Abstract: Wire electric discharge machining (WEDM) is a widely accepted non-traditional material removal process for manufacturing of components with intricate shapes. This is used in the fields of dies, molds; precision manufacturing and contour cutting etc. In the present work, an investigation into the wire electric discharge machining of SS 304 is made. Type 304 stainless steel is the most common austenitic chromium-nickel stainless steel. Experimentation has been done using Taguchi's L_9 orthogonal array. Each experiment was conducted under different combinations of pulse on time, pulse off time and peak current. The optimum machining parameter combination was obtained by using the analysis of signal-to-noise (*S/N*) ratio, analysis of means and analysis of variance (ANOVA). Further, the level of importance of the machining parameters on response addendum length was determined by using ANOVA. The study shows that the Taguchi's method is suitable to solve the stated problem with minimum number of trails.

Keywords: Wire EDM, SS 304, Taguchi's Method and ANOVAs.

I. INTRODUCTION

WEDM is a thermo- electrical process in which material is removed by a series of sparks between work piece and wire electrode (tool). The part and wire are immersed in a dielectric (electrically non conducting) fluid, usually deionized water, which also acts as a coolant and flushes the debris away. The material which is to be cut must be electrically conductive.

In WEDM, there is no direct contact between work piece and tool (wire) as in conventional machining process, therefore materials of any hardness can be machined and minimum clamping pressure is required to hold the work piece. In this process, the material is eroded by a series of discrete electrical discharges between the work piece and tool. These discharges cause sparks and result in high temperatures instantaneously, up to about 10000º C. These temperatures are huge enough to melt and vaporize the work piece metal and the eroded debris cools down swiftly in working liquid and flushed away. In 1969, the Swiss firm Agie produced the world's first wire EDM machine. These early machines were extremely slow but today, machines are equipped with automatic wire threading and can cut over 20 times faster, Carl Sommer and Steev Sommer. The effectiveness of the whole process depends on number of input process parameters such as pulse on time, pulse off time, servo voltage, peak current, dielectric flow rate, wire feed, and wire tension. The important machining responses include material removal rate (MRR), surface roughness (Ra), Kerf (width of cut), wire wear ratio (WWR) and surface integrity factors. In this paper description of various process parameters and their influence respective response have been presented. Literature is classified based on the response parameters. Different modeling and optimization methods proposed by various researchers are also discussed. Finally the recommendations and future trends in WEDM research have been out.

II. LITERATURE REVIEW

Xuehua et al. [1] manufactured a hot extruded 7075 aluminum alloy micro gear. According to this micro gear is an important actuating components used widely used in micro electromechanical system.It is important to develop micro forming techniques for micro-gears manufactured from high-strength commercial alloys. Dong Wang et al. [2] formed a micro gear with Zr-Cu-Ni-Al bulk metallic glass. The experimental results were simulated using a finite element simulation software DEFORM 3D, and the forming load is predicted at different processing parameters. Meanwhile, the filling stages of bulk metallic glass in the micro-gear mold cavity are investigated by finite element simulation and experiment. S.Plaza [3] had presented a paper which reports that original models for the prediction of angular error in wire-EDM taper-cutting. K.P.Rajurkar and W.M.Wang [4] had presented a paper which reports a WEDM sparking frequency monitor developed to detect the thermal load for on line control to prevent the wire from rupture. M.Kunieda et al.[5] had presented a paper which aims to show the prospects of electrical discharge machining (EDM) technology by interrelating recent achievements in fundamental studies on EDM wi th newly developed advanced application technologies. B.Lauwers et al. [6] had investigated Wear Behaviour and Tool Life of Wire-EDM-ed and Ground Carbide Punches .This paper describes and discusses the wear behaviour and tool life of a cemented carbide punch produced in eight different qualities.Shunsuke Tomura and Masanori Kunieda [7] clarifies the mechanism of how electromagnetic force applied to the wire electrode in wire electrical discharge machining (wire-EDM) is generated. This electromagnetic force is caused not only by DC component but also by AC components of the discharge current supplied to the wire.Mu-Tian Yan and Yi-Peng Lai [8] had studied about Surface quality improvement of wire-EDM using a fine-finish power supply. In this study, a transistor-controlled RC-type fine-finish power supply for wire-EDM has been developed. The developed power supply provide low discharge energy pulses with a frequency of 500kHz. Discharge duration as short as 150ns and peak current as low as 0.7 A can be obtained through the adjustment of the capacitance and current-limiting resistance in the discharge circuit, respectively. Y.S.Liao et al.[9] had studied to achieve a fine surface finish in Wire-EDM. J.A.Sanchez et al.[10] had made an investigation on the influence of cutting speed limitation on the accuracy of wire-EDM corner-cutting .T.A.Spedding and Z.Q.Wang [11] had studied on modelling of wire EDM process. L.Li et al.[12] published an paper on surface integrity characteristics in wire-EDM of inconel 718 at different discharge energy. P.Haas et al. [13] had studied the particle hydrodynamics of the electrical discharge machining process, physical consideration and wire EDM process improvement.Gupta, K. And Jain,N.K.[14] presented a paper which presents the manufacturing of high quality miniature spur gears of brass by wire- EDM. Effects of four WEDM parameters i.e. voltage, pulse-on time, pulse-off time and wire feed rate on five responses namely profile error, pitch error, average roughness, maximum roughness and material removal rate are studied. Anmol Bhatia et al.[15] ,work deals with the optimization of surface roughness while machining high carbon chromium steel on Wire Electrical Discharge Machining using brass wire.Kapil Gupta et al.[16] presented a paper that reports on exploring the wire electrical discharge machining process for manufacturing the high quality meso gears made of brass. M.Durairaj et al.[17] summarizes the grey relational theory and Taguchi optimization technique, in order to optimize the cutting parameters in Wire EDM for SS304. The objective of optimization is to attain the minimum kerf width and the best surface quality simultaneously and separately.

III. EXPERIMENT

EXPERIMENTAL SETUP FOR TESTING

In this set up main focus is on testing Gear manufacturing of stainless steel (SS-304). In Stereo zoom microscope machine that was prepared after gear manufacturing is visually inspected for any kind of dimension.

WIRE EDM MACHINE

Wire EDM's are manufactured in various sizes and styles of flush or submerged type machines to fit the needs of the consumer. Large scale EDM's can handle work pieces weighing over ten thousand pounds and can cut over twenty inches thick. Automatic Wire Threaders (AWT) are usually standard equipment on most models. In addition to the X-Y table travels, wire EDM's have U / V travels for providing the movement to cut tapers. Most machines can cut tapers of 20-30 degrees depending on workpiece thickness.

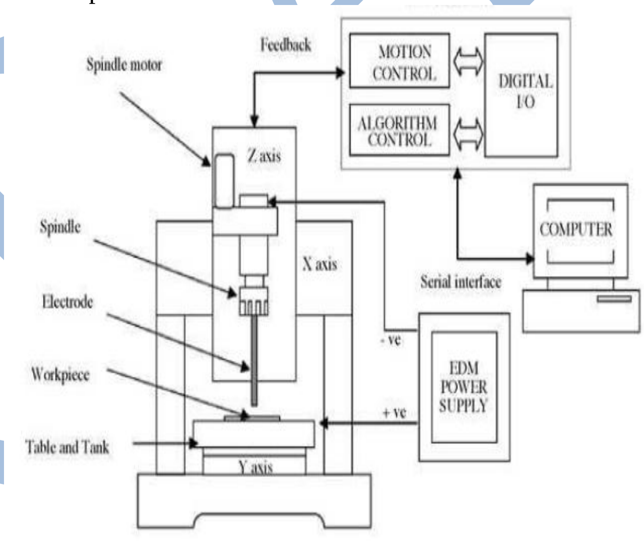

Figure 1. Experimental Setup

Design of experiments

It is based on Taguchi's concept which have been in developed into an engineering method of quality improvement referred to as quality engineering in Japan and as robust design in the west, which is discipline engineering process that seeks to find best trade off a product design. Concepts technique used in robust design Taguchi's concept such as "quality", S/N Ratio, Orthogonal arrays Degree of freedom and analysis of variance " may be synthesis in engineering studies. The quality lose function is considered as an innovative means for determining the economic advantage of improving system safety or operational safety .orthogonal arrays are used to study many parameters simultaneously with a minimum of time and resources to produce an overall pictures for more detailed safety based design an operational decision making. The Signal to noise ratio is employed to measure quality. L9 mixed arrays table was chosen for the experiment. Three controlling factors having three levels (small, medium and large)were selected as controlling

factors:
1. Pulse on time
2. Pulse off time
3. Current

Table 1 Machining factors and their levels

Factors	Level-1	Level-2	Level-3
Pulse on time	15	20	25
Pulse off time	4	5	6
Current	3	4	5

Orthogonal arrays

Taguchi's has developed a system of tabulated designs (arrays) that allow for the maximum number of main effects to be estimated in an unbiased (orthogonal) manner, with a minimum number of runs in the experiment. Orthogonal arrays [6] are used to systematically vary and test the different levels of each of the control factors. Commonly used as includes the L4, L9, L12, L18, and L27. The columns in the OA indicate the factor and its corresponding levels, and each row in the OA constitutes an experimental run which is performed at the given factor settings. Typically either 2 or 3 levels are chosen for each factor. Selecting the number of levels and quantities properly constitutes the bulk of the effort in planning robust design experiments.

Exp no.	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

5 Signal to noise ratio and ANOVA approach

The S/N ratio developed by Dr. Taguchi [27] is a performance measure to choose control levels that best cope with noise. The S/N ratio takes both the mean and the variability into account. In its simplest form, the S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The S/N equation depends on the criterion for the quality characteristic to be optimized. While there are many different possible S/N ratios, three of them are considered standard and are generally applicable in the situations below:

• Biggest-is-best quality characteristic (strength, yield),
• Smallest-is-best quality characteristic (contamination),
• Nominal-is-best quality characteristic (dimension).

In addition to the Signal to Noise Ratio (S/N ratio), the obtained results have been tested using statistical Analysis of Variance (ANOVA) with Pareto chart to indicate the impact of process parameters on surface roughness. The reason of combining Pareto chart with Analysis of Variance was to detect causes applying the principle that 80 percent of the problems usually stem from 20 percent of the causes. Pareto ANOVA technique of analysis has been used in this experimentation to analyze data for process optimization in past research also. Pareto ANOVA is a simplified ANOVA method, which uses Pareto principle. It is a quick and easy method to analyze result of parameters design. It does not require an ANOVA table and therefore, does not use F-test. The calculations of these tables are done by the use of standard orthogonal arrays. The preferred parameter settings are then determined through analysis of the "signal-to-noise" (SN) ratio where factor levels that maximize the appropriate SN ratio are optimal. There are three standard types of SN ratios depending on the desired performance response.

4 RESULTS AND DISCUSSION

In order to assess influence of various factors means and signal to noise ratio for each control factor are to be calculated. Levels of input parameters (i.e. pulse on time, pulse off time and current) are selected as per orthogonal array selector and results of analysis of micro gear for each trial are tabulated below..

4.1 Analysis for Micro Gear For Addendum length-

Table-2 L9 TABLE

A	B	C	Deviations	S/N Ratio
1	1	1	0.083	21.6184
1	2	2	0.099	20.0873
1	3	3	0.058	24.7314
2	1	2	0.093	20.6303
2	2	3	0.075	22.4988
2	3	1	0.078	22.1581
3	1	3	0.067	23.4785
3	2	1	0.095	20.4455
3	3	2	0.091	20.8192

Table 3 Taguchi Orthogonal Array Design for Addendum L9

Table 4 Response table for signal to noise ratios (Smaller Is Better)

Level	A	B	C
1	22.15	21.91	21.41
2	21.76	21.01	20.51
3	21.58	22.57	23.57
Delta	0.56	1.56	3.06
Rank	3	2	1

4.2 Main Effects Plot for SN Ratios -Initially the experimental results were used to obtain S/N Ratios for the performance characteristics to find a desirable result with the best performance and smallest variance.

Fig 4.1 depicts the main effect plot for S/N ratio. It can be seen from Fig 4.1 that within the range of investigated input parameters, the optimal combination of the parameters of Addendum is ***A*₁*B*₃*C*₃**, i.e., at pulse on time (A_3), pulse off time (B_3) and current (C_1).

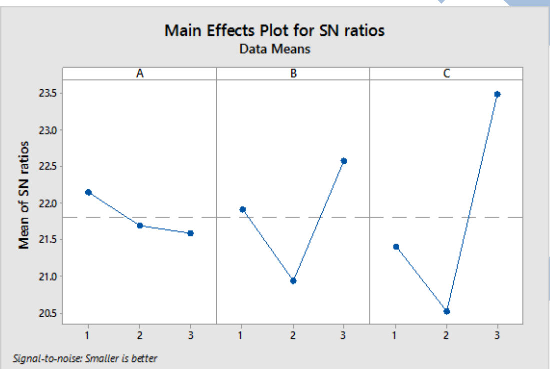

Fig-2 Plot for SN Ratio

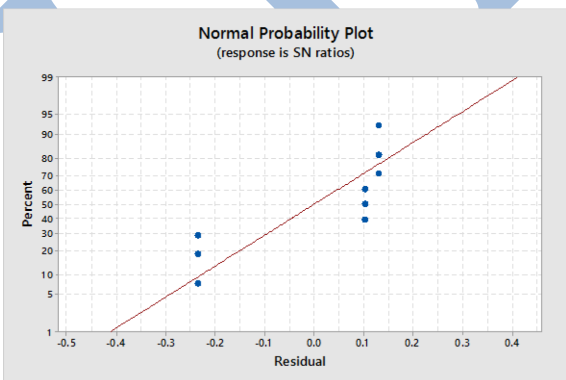

Fig-3 Normal Probability Plot For SN Ratio

4.4 Results of Analysis of Variance

Table 5 Results of Analysis of Variance:

Source	DF	Seq SS	Adj SS	ADJ MS	F	P	% Distribution
A	2	0.4987	0.4987	0.24933	3.24	0.236	82.51
B	2	3.6743	3.6743	1.83713	23.86	0.040	13.99
C	2	14.8235	14.8235	7.41173	96.28	0.010	3.50
Residual Error	2	0.1540	0.1540	0.07698			
Total	8	19.1503					

The analysis of variance (ANOVA) was conducted to study the significance of machining parameters on Addendum length based on their P-value and F-value at 5% level of significance. The ANOVA results are shown in Table 4.3. It can be seen from Table 4.3 that the pulse on time and pulse off time significantly affects the addendum length as F calculated value is more than the tabulated F value ($F_{0.05}$, (2,2) = 19.00). However, based on the percentage contribution of the machining parameters shown in Tale 4.3, it is found that % contribution of pulse on time is maximum (82.51%) followed by pulse off time (13.99%) and current (3.50%).

5. CONCLUSION

This work presents an experimental study in which WEDM is performed on material SS304 for the machining of micro gear. Trial run was conducted to establish the range of selected parameters. Subsequently pulse on time at three level , pulse off time at three levels and current at three levels are considered and 9 experiments as per the experimental plan of Taguchi's experimental design i.e. L_9 OA are conducted . response variable namely Addendum length is measured. Signal to noise ratio for each response variable is computed. Subsequently, analysis of variance is used to obtain the percentage contribution of the parameters.

The analysis of mean is performed to obtain optimum level of the machining parameters for multi performance characteristics.

With respect to the present study the following conclusion are drawn.

- The optimum combination of machining parameters and their levels for decreasing the deviation in addendum length is A_1 B_3C_3.
- the percentage contribution of pulse on time is maximum i.e. 82.51%. Therefore it is most important and significant factor affecting the addendum length. The next important parameter is pulse off time and its percentage contribution is 13.99 and it is followed by the current .

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