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Analysis of Material Removal in WEDM Operation on E0300 Alloy Steel through Channel Coding

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Abstract

Wire-electro discharge machining (WEDM) has become an important non-traditional machining process, widely used in the aerospace, nuclear and automotive industries. The electrode which is used for WEDM is a tiny flexible brass wire, therefore in WEDM machining process, the wire behaviors and the influence of parametric conditions on the work piece needs to be well estimated. The investigations and simulations of Wire-EDM are useful for different machining conditions in practical scenario. The channel coding methodology base approach is utilized to simulate the machining parameters for better material removal rate (MRR) of the work piece of E0300 die steel. In the present work a binary symmetric channel (BSC) is used for the information that can be transmitted through the channels with encoding and decoding techniques. The various WED machining parameters selected are TON, TOFF, IP, VP, WF, WT and SV. Mathematical models are also developed to correlate the inter relationship of important factors which invariably helps for prediction of MRR during machining. The objective of this development is to estimate the MRR based on channel coding approach and verification of the results with the experimental machining parametric settings. The paper also highlights the various test results that confirm the ability of the proposed system for analyzing the effect of the various process parameters of WEDM during machining of E0300 alloy steel. The investigation also describes a simulating procedure, developed algorithms and few analyzed results of Wire EDM. The simulated values of the machining parameters obtained through the approach can be recorded and organized for a better and effective database system.

***Keywords**:* WEDM, channel coding, MRR, machining parameters, alloy steel.

1. Introduction

Wire-electro discharge machining (WEDM) is a well established machining process for metallic and hard materials. The potential of WEDM is very popular in the fabrication of moulds and dies. The fundamental principle of the WEDM process is similar to electrical discharge machining (EDM) and described elsewhere [1 - 4]. However, the rigid solid tool is replaced with continuously rolling thin wire, usually made of brass. The portion of wire generating the electrical sparks is kept under tension (WT) in between a pair of guide ways. The wire under tension is continuously feed through spool; which machine the workpiece with spark generated in between the wire (cathode) and the workpiece (anode). The machining of the workpiece is because of electro erosion between tool and the workpiece through a dielectric (deionized water). The eroded material is continuously flushed with the dielectric flow controlled through a pair of nozzle, placed at two ends of the tensioned wire. The sparks are generated due to avalanche breakdown of dielectric in between a narrow gap of cathode and anode. The time for which the sparks are active and inactive are preset as pulse ON time (TON) and pulse OFF time (TOFF), respectively. The effectiveness of spark generation is expressed in dimensionless parameter as duty cycle as a ratio of TON to TON + TOFF; expressed in percentage (%). In such complex and sensitive working environment the material removal rate (MRR) from the anode (workpiece) is critical, which leads to large machining time. The performance evaluation of WEDM system is an important issue unlike other complex machining processes.

The paper highlights the effective use of channel coding methodology to analyze the MRR of workpiece made of die steel material. An encoding and decoding technique of binary symmetric channel is used to process the information related to MRR. An attempt is made to model the process output (MRR) through corresponding binary codes of preset machining inputs. The performance metric of digital processing is overviewed in the area of machining of material in a single pass.

2. Experimentation

The experimental trials were performed on a four axis WED machine of Electronica make (model: super cut 734). The worktable movement was computer controlled (CNC: computer numeric control). The cutting path was linear and the process was analysed for a single cut on the workpiece. The maximum current required for machining workpiece during time (TON) is preset on WED machine as pulse peak current (Ip). The working range of seven parameter were chosen for experimental investigation are TON, TOFF, Ip, Vp, WF, WT, SV as illustrated in Table 1.

However, other parameters FR, Wo, Wp, Vc are set at constant value before the start of experimental trials.

A brass wire of 250 μm diameter was used as tool electrode (cathode). The work piece material used is E0300 alloy steel (anode). The hardness of E0300 alloy steel is RB 95 and density 7.72 Kg/mm^3. Table 2 describes the chemical composition of E0300 alloy steel used for experimentation.

The spark generation erodes both the brass wire and workpiece. However, due to spool rotation the brass wire is new during the machining operation. The energy imposed on workpiece depends on the product of TON and Ip. A Taguchi L_{18} (2^1 x 3^7) mixed design was used to plan systematic non-repetitive experimental trials. The experiments trials were conducted in unique 18 ways (MRR1) with one repetition for each trial (MRR2). A signal to noise ration (S/N) was used to express the quality characteristic of the output MRR in dB (decibel) [5 - 7]. A larger the better MRR is desirable for reducing the machining time of the E0300 die steel.

Table 1. Parameters selection for experimental investigation

Parameters	Working Range	Unit
Pulse on time (TON)	1 to 1.1	m.s
Pulse off time (TOFF)	14 to 16	m.s
Pulse peak current (Ip)	10 to 100	A
Pulse peak voltage (Vp)	75 to 100	V
Wire feed velocity (WF)	5 to 7	m/min
Wire tension (WT)	8.8 to 13.5	N
Spark voltage (SV)	3 to 16	V
Dielectric flow rate (FR)	5	lpm
Wire offset (Wo)	150	mm
Dielectric pressure (Wp)	1.47 x 106	N/m^2
Cutting speed (Vc)	2	mm/ min

Table 2 Chemical compositions of E0300 alloy steel

Elements	Cr	C	Mn	Si	W	S	P	Mo	Ni
% composition	1.33	0.87	0.76	0.24	0.15	0.08	0.04	0.03	0.02

3. Channel Coding for MRR

An experimental channel coding methodology base approach is utilized to simulate the machining parameters for material removal rate (MRR) of the work piece of E0300 die steel. A binary symmetric channel (BSC) is used for the information that can be transmitted through the channels with encoding and decoding techniques. The work of various researchers shows different coding system for analyzing the performance of the system [8 -10]. However, the BSC focuses on the altering and processing of binary information without the loss in the generalization of the data. A basic schematic of the BSC and the supporting components are shown in Fig. 1. The data information MRR are converted to its binary codes and thereafter transferred to BSC or additive white Gaussian noise channel (AWNGC) for data processing. The AWNGC is however based on the insertion and deletion of the binary codes, which makes the WEDM data processing complex. The corrupted binary codes of MRR are processed by decoder and are compared with its original form. The comparison is made on the basis of bit error, bit error rate (BER), bit entropy and packet error.

The bit error is based on comparing bit to bit variation while the BER is used to analyse and compare the data for better repeatability of the process. Bit error is thus expressed as the ratio of error numbers to the total numbers of bits transferred. The BER helps to identify the rate of occurrence of error during the machining process, on the basis of its output data. The codes for simulation codes are customized statistically and it is applied on WEDM process to assess the quality degradation of the machining output in terms of MRR. The quality characteristics involve all the system elements from input (TON, TOFF, Ip, Vp, WF, WT, SV) to the desired output (MRR), which gives the actual performance of the system. The errors are considered to be of random nature and statistically following a Gaussian probability function.

The bit entropy reflects the process uncertainty and shows the capacity of BSC and is expressed in logarithmic form as, -BER log2 BER – (1-BER)log2(1-BER). The BSC capacity is expressed as 100% minus the bit entropy. The BER when is zero reflects the maximum bit entropy of 100%. The packet error (in %) highlights the chance of interference of noise when the bit flows from one end to other and is expressed as 1 – (1-BER) bit used. In the present work, the total bit for a MRR output is restricted to 8 bit. The

BER when extends beyond the threshold of 50% the binary codes are interchanged (1 to 0 and vice versa) as a data processing correction step.

4. Results and Discussion

The experimental outputs are recorded as per the Taguchi's L_{18} mixed orthogonal array design and are shown in Table 3. The pair of output (MRR1 and MRR2) is recorded for similar set of inputs and was coded to its binary value for effective processing through channel coding.

The experimental performance of the process highly depends on the extent and quality of the information. The BER obtained for the 18 trials are analyzed and shown in Fig. 2. The various aspects analyzed are for (i) minimum MRR (Min), (ii) average MRR (Avg) and (iii) maximum MRR (Max).

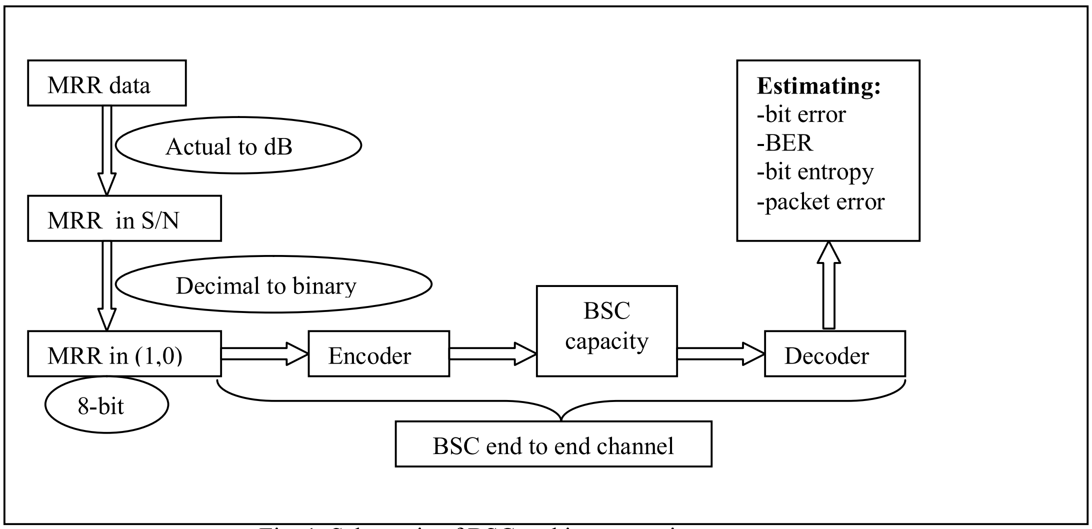

Fig. 1. Schematic of BSC and its supporting components

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Table 3. Experimental observations as per Taguchi's L_{18} (2^1 x 3^7) design

	A	B	C	D	E	F	G	S/N (dB) ratios for		Binary values for	
No.	VP	TON	TOFF	IP	WF	WT	SV	MRR1	MRR2	MRR1	MRR2
1	1	1	1	1	1	1	1	17.002	17.128	10001	10001
2	1	1	2	2	2	2	2	16.77	16.78	10000	10000
3	1	1	3	3	3	3	3	16.527	16.583	10000	10000
4	1	2	1	1	2	2	3	16.448	16.456	10000	10000
5	1	2	2	2	3	3	1	16.008	16.068	10000	10000
6	1	2	3	3	1	1	2	15.882	15.98	01111	01111
7	1	3	1	2	1	3	2	16.044	16.094	10000	10000
8	1	3	2	3	2	1	3	16.16	16.195	10000	10000
9	1	3	3	1	3	2	1	15.989	16.167	01111	10000
10	2	1	1	3	3	2	2	16.021	16.028	10000	10000
11	2	1	2	1	1	3	3	15.895	15.925	01111	01111
12	2	1	3	2	2	1	1	15.645	15.692	01111	01111
13	2	2	1	2	3	1	3	15.674	15.683	01111	01111
14	2	2	2	3	1	2	1	15.437	15.515	01111	01111
15	2	2	3	1	2	3	2	14.809	15.034	01110	01111
16	2	3	1	3	2	3	1	14.132	14.141	01110	01110
17	2	3	2	1	3	1	2	13.497	13.578	01101	01101
18	2	3	3	2	1	2	3	12.753	12.774	01100	01100

The MRR in WEDM is small and was recorded in terms of S/N ratio to convert into binary codes on 8 bit basis. On the basis of the requirement of minimum MRR for better surface finish during machining, the results show intermittent and constant trend. It shows better repeatability of WEDM process when compared on the basis of minimum MRR. At the later part of experimental trial (trial no. 11 to 18), the rate of occurrence of the error during machining was dropped relatively to its lower values. As a compromise for better surface finish and better MRR, the comparison is based on the basis of average MRR (Avg). In such case the chances of introduction of error rate increases, especially during initial trials. The chance of occurrence of error is almost negligible of trial number 6, at which the input setting values were Vp: 75 V, TON: 1.05 m.s, TOFF: 16 m.s, Ip: 100 A, WF: 5 m/min, WT: 8.8 N and SV: 9 V. The maximum MRR for fast machining is desired in WEDM, which results in similar behavioral pattern as for minimum MRR case, but with reverse and sharp changes from one trial to other.

The variation in bit entropy for different MRR consideration is shown in Fig. 3. The higher value of bit entropy for minimum MRR consideration is observed to be more random. As per entropy assumption the random behavior gives better prediction than a structured behavior. The machining process operates in for less MRR support the claims from the later part of experimental trials; entropy drop and the process less uncertain. The maximum MRR condition shows lower bit entropy (less uncertainty) for initial trials which increases on later part of trials (more random). It reflects that the lower number of experimental trials could be preferred for low MRR and vice versa. In a compromising situation (Avg) the higher bit entropy is biased for initial part of the experimentation, which shows the more confidence in initial set of data. The capacity of BSC is reverse to the bit entropy and shown in Fig. 4. It also reflects the highest rate of the data transfer rate for consistent performance of the machine is at lower experimental trials.

The packet error highlights the number of bit wrongly generated out of 8 bit processed. The variation during the experimental trial is shown in Fig. 5. The error is determined to correct the faulty processing of data and minimize an error in predicting the output MRR value. The packet error is highest for the case of maximum MRR at later stage and minimum MRR at initial stages. It shows that the bit data could be corrected from 1 to 0 or vice versa for effective correction in processing of data. In consideration to the case of requirement of average MRR, the packet error is highest for initial set of trials. The similar pattern is observed in the analysis of BER. However, for maximum MRR case the pattern of BER and packet error does not match. The correction in the bit is thus preferred to be applied for the later part of experimental trials.

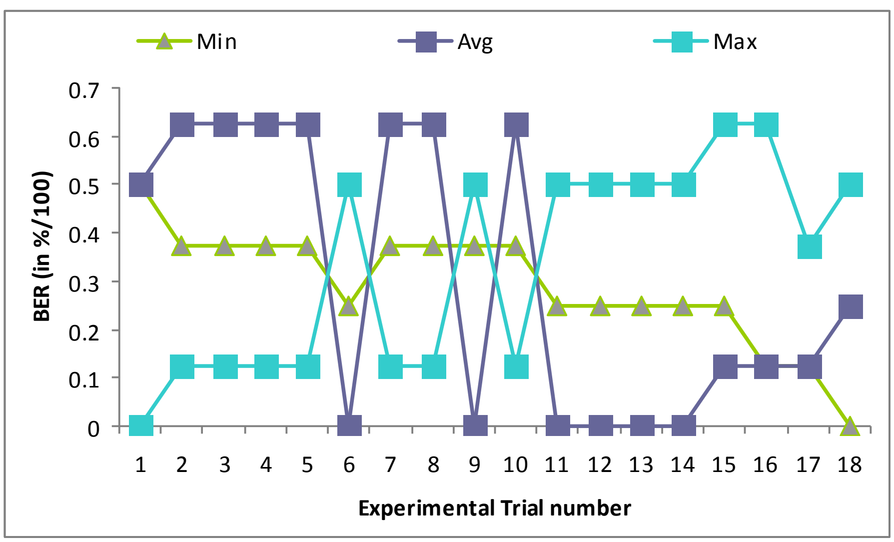

Fig. 2. BER for different consideration of MRR output

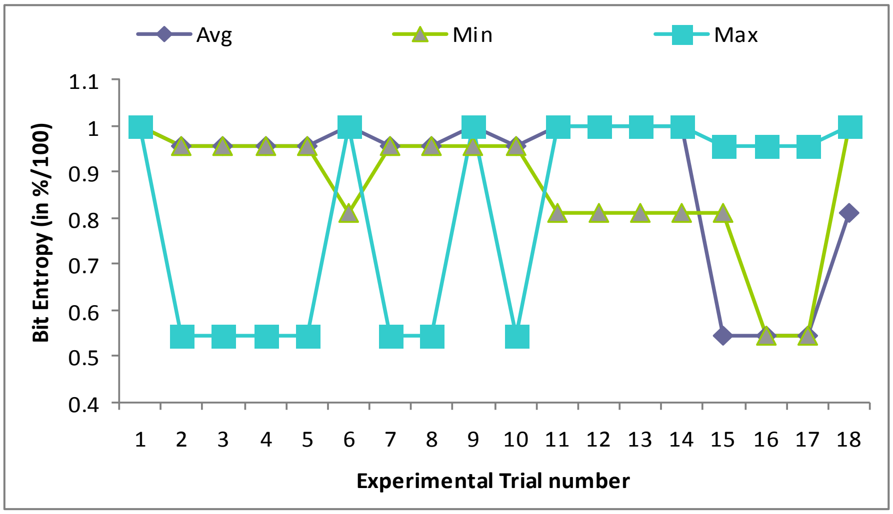

Fig. 3. Bit entropy for different consideration of MRR output

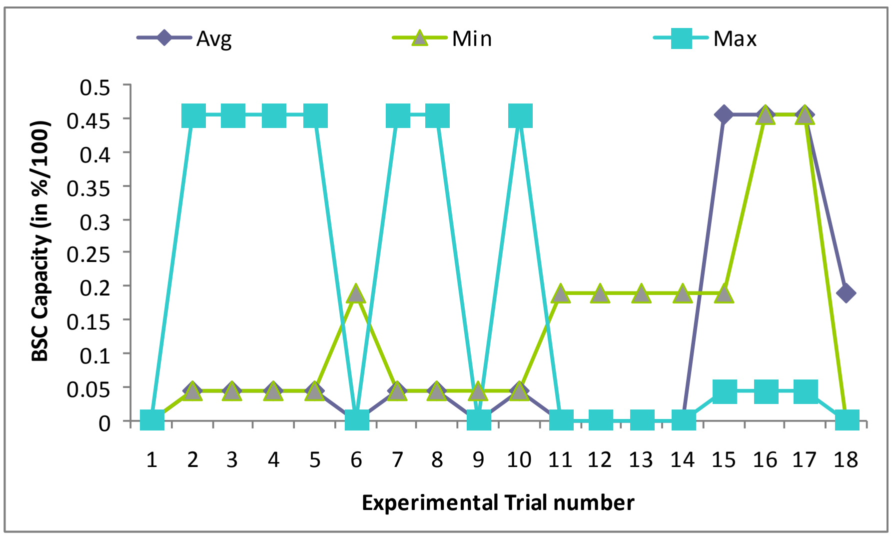

Fig. 4. BSC capacity for different consideration of MRR output

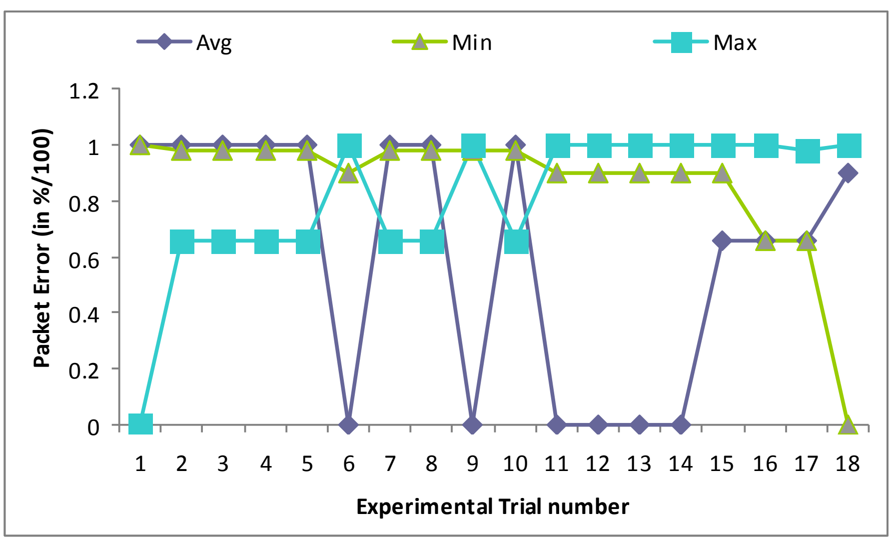

Fig. 5. Packet error for different consideration of MRR output

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5. Conclusions

A methodology of data processing using binary symmetric coding is applied on WEDM process. The present system (WEDM) shows better repeatability in generating the output data in terms of MRR for initial setting of Taguchi's experimental mixed orthogonal array. The small value of BER shows a better S/N ratio of the overall system under the assumed parameters and constraints. It was observed that at high BER most of the bits are in error, which was normalised by interchange of binary numbers. At higher BER the data processing becomes erratic and the conclusive results are erratic. The other performance estimating criteria in terms of bit error, bit entropy and packet error were supportive to the BSC mode of processing of data. The coding system helps to advice on the qualitative and quantitative evaluation of the machining performance.

6. References

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