

A COMBINED ANALYSIS OF SURFACE ROUGHNESS OBTAINED BY EDM ACCORDING TO TWO DIFFERENT ISO STANDARDS

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ABSTRACT:

The application of two topological and morphological surface metrology standards namely, motif combination (ISO 12085: 1996) and "R_k" family of bearing curve parameters (ISO 13565-2:1996) on EDMed surfaces is described in the present study. The machining conditions were varied over a representative range from roughing to semi-finishing of Ck60 carbon steel parts. Close correlation was detected between the motif parameters and some "R_k's" and the machining conditions, and by applying analysis of variance and response surface methodology to the experimental data, predictive models possessing high coefficients of determination were developed. Using the postulated models, the appropriate conditions for successful finish can be selected, as well as functional surface characteristics are quantified.

KEYWORDS: engineering surface, roughness, motif combination parameters, bearing (Abbott) curve, ISO 13565-2 parameters, response surface modeling, EDM.

1. INTRODUCTION

Electro-Discharge Machining (EDM) is an unconventional machining process that manufactures with high precision and versatility electrically conductive materials regardless of their mechanical properties. EDM is based on removing material from a component through an induction of a series of electrical discharges caused by an electrode standing for the tool. The resulting surface roughness has the appearance of a network of randomly sized and spaced overlapping craters [1].

It is well established that surface roughness obtained by various machining processes, apart from being a microgeometric property of the product within prescribed limits, affects the tribological function of the surface.

Surface texture characterization and evaluation has constituted a major metrological problem over the years, combined to increasing high precision and operation requirements. This fact is attributed to the usually complicated form of surface roughness and the need to obtain a satisfying description of the profile globally and at various levels, as well.

The most popular standardization system in surface metrology is the central line system "M" with its current version ISO 4287:1997

[2], but it appears unsatisfactory in some functional cases. For this purpose, two other standards have been developed, and will be discussed in the following; see also Ref. [3].

The surface motif combination (ISO 12085: 1996) [4] is a topological method of analyzing surface texture. It gives a graphical evaluation of surface profile without filtering waviness from roughness. A motif consists of the portion of a profile between two peaks and the final combination of these motifs eliminates "insignificant" peaks and retains "significant" ones. As a consequence, this method determines the upper points of the profile, which have functional importance by an envelope-based algorithm [5, 6]. The definition of the corresponding parameters is given in Table 1. Only roughness motifs will be considered in the present study.

Morphological and function oriented roughness characterization is introduced by the ISO13565-2:1996 standard [7] through the "R_k" family of parameters (Table 2), which describe the shape of the relevant Abbott curves, being also sensitive to profile form [8, 9].

Except from the consideration of more roughness parameters it would be more useful to measure surface characteristics of EDMed parts because of the nature of the irregularities mentioned above, resulting in

surface morphologies completely different when compared with the ones produced by conventional machining processes.

Table 1 The motif (R & W) parameters

Parameters	Description
R	Mean depth of roughness motifs
R_x	Maximum depth of roughness motifs
A_r	Mean spacing of roughness motifs
W	Mean depth of waviness motifs
W_x	Maximum depth of waviness motifs
W_{te}	Maximum depth of the waviness profile
A_w	Mean spacing of waviness motifs
K_r	Mean slope of roughness motifs
K_w	Mean slope of waviness motifs
P_t	Maximum depth of the raw profile

Table 2 The “R_k” family of parameters

Parameters	Description
R_k	Depth of the roughness core profile
R_{pk}	Top portion of the surface to be worn away
R_{vk}	Lowest part of the surface retaining the lubricant
MR1	Upper limit of the core roughness
MR2	Lowest limit of the core roughness

This study presents the application of these two methods in the analysis of surface textures of EDMed Ck60 steel plates. Pulse current and pulse-on time, considered to be the main machining variables, were varied over a representative range. The correlation of the roughness parameters defined in the aforementioned standards with the machining conditions is investigated using analysis of variance (ANOVA; moreover, for formulating models, when possible, the response surface methodology (RSM) is applied.

2. EXPERIMENTAL

The workpiece material was a Ck60 plain carbon steel. EDMachining was performed on a HOSTEK SH-38GP (ZNC type) electro-discharge machine-tool with rectangular pulse generator of 30V working voltage (V_e) and 100 V open-circuit voltage. Experiments were conducted in a typical oil dielectric (BP250) with electrolytic copper being used as the tool electrode (anode).

The pulse current, I_e and the pulse-on time, t_p varied over a range from roughing to semi-finishing, namely: I_e : 5, 10, 20, 30 A and t_p : 100, 300, 500 μ sec, with constant duty-factor; thus resulting in 12 discrete pulse energies; the pulse energy is calculated by the formula: $W_e = V_e \cdot I_e \cdot t_p$ ($V_e = 30$ V). In all experiments conducted, the erosion process was considered as stable, since efficiency and stability were kept constant at a high level (85% - 95%).

The surface texture analysis was performed using a Rank Taylor-Hobson Surtronic 3+ profilometer equipped with the Talyprof software. The cut-off length was selected at 0.8 mm, whilst 40 measurements were conducted on every specimen (error less than $\pm 4\%$) at random directions, as it is known [9], that EDMachining generates geometrically isotropic textures.

3. RESULTS AND DISCUSSION

3.1 ANOVA results and modelling for motif parameters

From the ANOVA Table 3 it is evident that all the factors of the model, except the pulse current square, have physical and statistical significance on the variation of the R parameter; the major effect is exerted by the pulse current (a 61% contribution), followed by the interaction factor, the pulse-on time and the squared value of the latter (ranging from 12% to 10%).

The error associated with the analysis does not exceed 5%.

Table 3 Analysis of variance for R

Source	DF	SS	F	p	P(%)
I_e	1	1777.31	292.94	.000	60.99
t_p	1	324.00	53.40	.000	10.94
$I_e \cdot t_p$	1	364.26	60.04	.000	12.33
I_e^2	1	24.08	3.97	.062	0.62
t_p^2	1	305.02	50.27	.000	10.30
Error	18	109.21			4.82
Total	23	2903.88			100

Note: DF: degrees of freedom, SS: sum of squares, F: F-test, p: p-test, P(%) factor contribution

The coefficient of determination (R^2), for the corresponding model was estimated as $R^2 = 0.962$.

From the ANOVA results concerning R_x (Table 4) it is observed that only the pulse current and the pulse-on time exert physical and statistical significance on the R_x parameter, with contribution 58% and 17%, respectively. The other factors appear insignificant, taking values less than the error (12%); the higher value of the latter can be attributed to the relatively high scatter which maximum height roughness parameters show.

Table 4 Analysis of Variance for R_x

Source	DF	SS	F	p	P(%)
I_e	1	18164.6	114.74	.000	58.03
t_p	1	5310.8	33.55	.000	16.60
$I_e \cdot t_p$	1	2011.8	12.71	.002	5.97
$I_e \cdot I_e$	1	1280.9	8.09	.011	3.61
$t_p \cdot t_p$	1	1407.3	8.89	.008	4.02
Error	18	2849.5			1.77
Total	23	31024,9			100

Note: DF: degrees of freedom, SS: sum of squares, F:F-test, p: p-test, P(%) factor contribution

The coefficient of determination, for the corresponding model was estimated as, $R^2 = 0.908$.

In a similar way, according to Table 5, it was revealed by the ANOVA that the I_e and t_p factors have physical and statistical significance on A_r , whilst the other factors lie below the error value (8.5%).

Table 5 Analysis of variance for A_r

Source	DF	SS	F	p	P(%)
I_e	1	9018.0	201.5	.000	46.62
t_p	1	8204.8	183.3	.000	42.40
$t_p \cdot I_e$	1	386.3	8.63	.026	0.00
$t_p \cdot t_p$	1	468.2	0.46	.018	0.10
$I_e \cdot I_e$	1	899.3	0.10	.004	2.34
Error	18	268.5	4.70		8.54
Total	23	19245			100

Note: DF: degrees of freedom, SS: sum of squares, F: F-test, p: p-test, P(%) factor contribution

The coefficient of determination, for the corresponding model was estimated as $R^2 = 0.986$.

Regarding the K_r parameter variance, as obtained by the ANOVA (Table 6), all the factors, except $I_e \cdot I_e$, exert physical and statistical significance. The estimated error contribution is 6%.

The coefficient of determination for the corresponding model was estimated as, $R^2 = 0.962$.

Table 6 Analysis of variance for K_r

Source	DF	SS	F	p	P(%)
I_e	1	0.090864	314.58	.000	65.18
t_p	1	0,009168	31.74	.000	6.45
$I_e \cdot t_p$	1	0.020518	71.03	.000	14.32
$I_e \cdot I_e$	1	0.001554	5.38	.032	0.91
$t_p \cdot t_p$	1	0.010296	35.65	.000	7.05
Error	18	0.005199			6.09
Total	23	0.137599			100

Note: DF: degrees of freedom, SS: sum of squares, F: F-test, p: p-test, P(%) factor contribution

The corresponding response surface graphs which represent the obtained functional relationships are shown In Figures 1 to 4. All four parameters show increasing trends, when intensifying the machining conditions; see similar conclusions in Ref. [9].

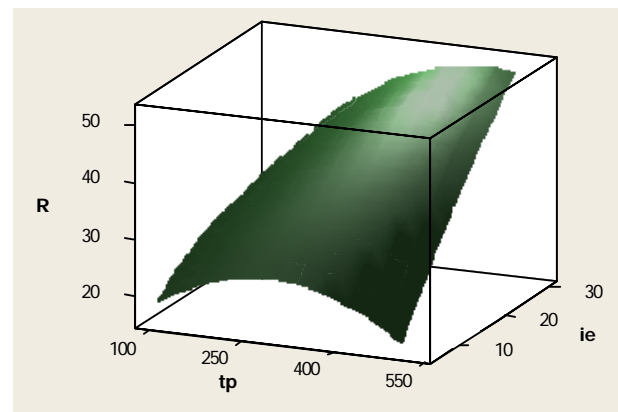


Fig.1: Estimated response surface of R variation

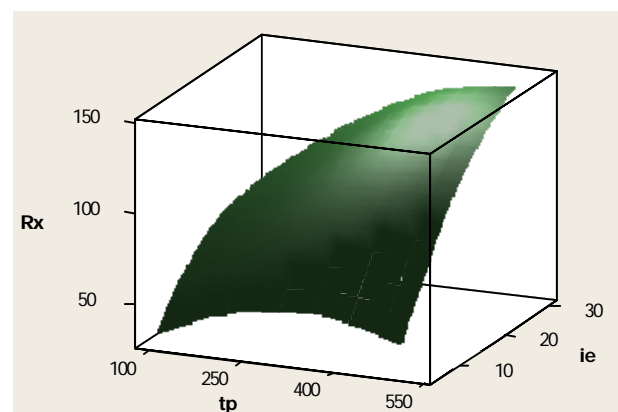


Fig.2: Estimated response surface of Rx variation

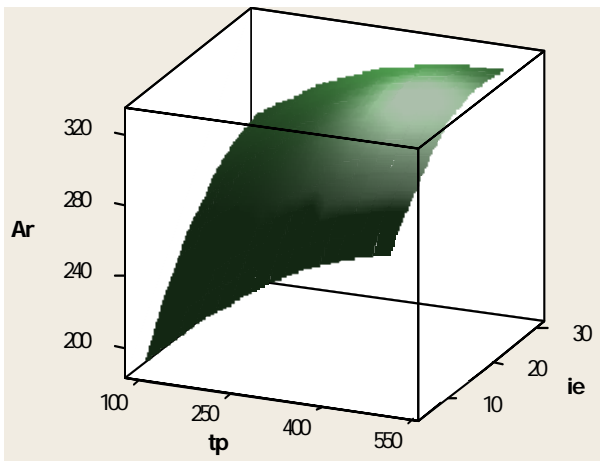


Fig. 3: Estimated response surface of A_r variation

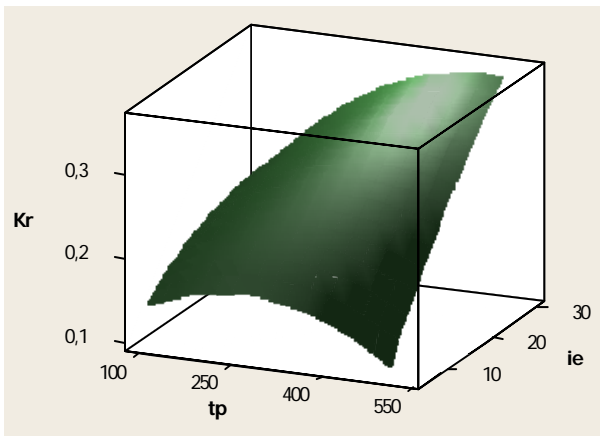


Fig. 4: Estimated response surface of K_r variation

3.2 ANOVA results and modelling for "R_k" parameters

In the case of the R_k parameter variance (Table 7) the only factors exerting physical and statistical significance are I_e (55%) and t_p (38%). The remaining factors take values well below the error (5%).

Table 7 Analysis of variance for R_k

Source	DF	SS	F	p	P(%)
I_e	1	29.150	108.34	.000	54.62
t_p	1	20.518	76.26	.000	38.29
$I_e \cdot t_p$	1	0.229	0.85	.399	0.00
$I_e \cdot I_e$	1	0.716	2.66	.164	0.84
$t_p \cdot t_p$	1	0.916	3.41	.124	1.22
Error	5	1.345			5.03
Total	10	52.875			100

Note: DF: degrees of freedom, SS: sum of squares, F: F-test, p: p-test, P(%) factor contribution

The coefficient of determination for the corresponding model was estimated as $R^2 = 0.974$.

Only the interaction factor appears significant on the variance of R_{pk} (Table 8); moreover the error contribution together with the coefficient of determination, 38% and 0.776 respectively, imply a fair model that is not accepted.

Table 8 Analysis of Variance for R_{pk}

Source	DF	SS	F	p	P(%)
I_e	1	0.5268	1.75	.243	3.37
t_p	1	0.6269	2.09	.208	4.86
$I_e \cdot t_p$	1	3.8931	12.96	.016	53.5
$I_e \cdot I_e$	1	0.0004	0.00	.972	0.00
$t_p \cdot t_p$	1	0.1630	0.54	.494	0.00
Error	5	1.5025			38.2
Total	10	6.7127			100

Note: DF: degrees of freedom, SS: sum of squares, F: F-test, p: p-test, P(%) factor contribution

The major effect on the R_{vk} parameter variance (Table 9) is exhibited by I_e (50%), followed by t_p (34%). The other factors appear insignificant with the error giving a 10% contribution.

Table 9 Analysis of Variance for R_{vk}

Source	DF	SS	F	p	P(%)
I_e	1	147.814	51.76	0.001	49.91
t_p	1	100.977	35.36	0.002	33.78
$I_e \cdot t_p$	1	20.918	7.32	0.042	6.22
$I_e \cdot I_e$	1	1.882	0.66	0.454	0.00
$t_p \cdot t_p$	1	4.579	1.60	0.261	0.59
Error	5	14.278			9.50
Total	10	290.447			100

Note: DF: degrees of freedom, SS: sum of squares, F: F-test, p: p-test, P(%) factor contribution

The coefficient of determination for the corresponding model was estimated as $R^2 = 0.951$.

The pulse current and the pulse-on time have physical and statistical significance on the MR1 parameter variance (Table 10) with their contribution almost balanced, 38% and 39% accordingly. The interaction factor takes a value (8.12%) slightly below the error (8.33%).

The coefficient of determination for the corresponding model was estimated as $R^2 = 0.958$.

Table 10 Analysis of Variance for MR1

Source	DF	SS	F	p	P (%)
I_e	1	46.039	46.52	.001	38.03
t_p	1	47.336	47.83	.001	39.12
$I_e \cdot t_p$	1	10.602	10.71	.022	8.12
$I_e \cdot I_e$	1	3.859	3.90	.105	2.43
$t_p \cdot t_p$	1	5.692	5.75	.062	3.97
Error	5	4.948			8.33
Total	10	118.477			100

Note: DF: degrees of freedom, SS: sum of squares, F: F-test, p: p-test, P (%): factor contribution

As in the case of R_{pk} , the estimated correlation regarding the MR2 parameter is fair ($R^2=0.759$) and along with the high contribution of error (41%) (Table 11) it is suggested that the formulation of a model is not feasible.

Table 11 Analysis of Variance for MR2

Source	DF	SS	F	p	P (%)
I_e	1	49.31	2.47	.177	7.06
t_p	1	58.64	2.93	.147	9.31
$I_e \cdot t_p$	1	197.01	9.86	.026	42.64
$I_e \cdot I_e$	1	2.21	0.11	.753	0.00
$t_p \cdot t_p$	1	8.03	0.40	.554	0.00
Error	5	99.94	19.99		40.99
Total	10	415.14			100

Note: DF: degrees of freedom, SS: sum of squares, F: F-test, p: p-test, P (%): factor contribution

The relevant response surface graphs that illustrate the aforementioned models are presented in Figures 5 to 7. It is evident that all three parameters show increasing trends, when I_e and t_p increase.

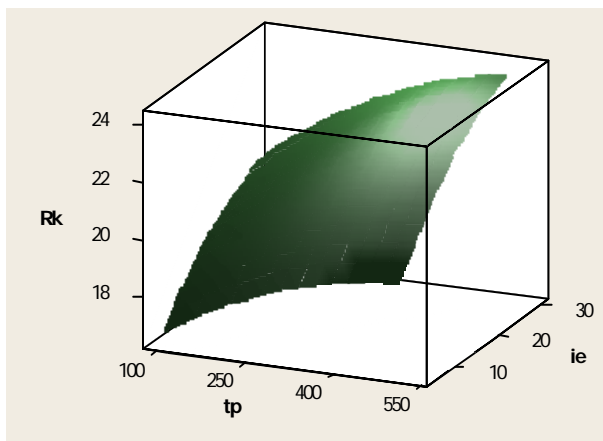


Fig. 5: Estimated response surface of R_k variation

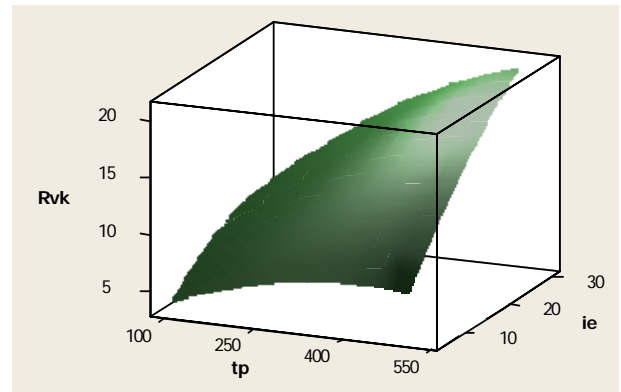


Fig. 6: Estimated response surface of R_{vk} variation

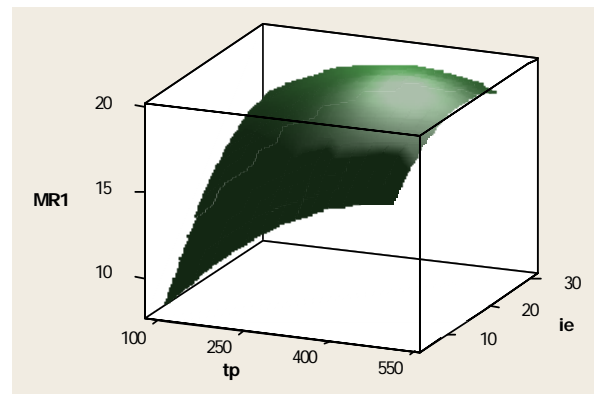


Fig. 7: Estimated response surface of MR1 variation

5. CONCLUSIONS

1. The motif parameters increase monotonously, when pulse current and/or pulse-on time increase. This behaviour implies that roughness amplitude, steepness and spacing are pronounced, when increasing the machining conditions.
2. From the ANOVA results it is observed that the highest physical and statistical significance on the variance of all the motif parameters is exhibited by pulse current (a percentage contribution ranging approximately from 47% to 65%), followed by pulse-on time (6.5% - 42.5% approximately).
3. Relevant models were formulated via response surface methodology characterized by high degrees of determination with the machining conditions I_e and t_p ($0.90 < R^2 < 0.98$).

4. The estimated response surface graphs illustrate these functional relationships and enable optimization of the machining conditions for given finish requirements, expressed by motif parameters.
5. As far as the description of bearing curves by the set of R_k parameters is concerned, it is indicated that the R , R_{vk} and $MR1$ parameters increase with increase in the machining conditions. The meaning of this is that the core roughness amplitude and the portion of the surface for oil retention enlarge when intensifying the machining conditions. Of course, this fact appears favourable but the maximum roughness height must be considered as a constraint.
6. The ANOVA revealed that as in the case of the motif parameters, I_e exerts the major physical and statistical significance on the variance of the "R_k's" parameters (from 55% to 38% approximately). A secondary influence was exhibited by t_p (34% to 39%). The correlation proved to be very high ($0.96 < R^2 < 0.97$). Two parameters, R_{pk} and $MR2$, exhibited fair correlation and were not finally modelled.
7. The obtained relevant response surface graphs may be used as charts for appropriate selection of machining conditions, when function of the surface is regarded.
8. On the basis of the findings of the present study, both motif and "R_k" parameters can provide an adequate description of crucial characteristics, both morphological and functional, of EDMed surface roughness profiles in relation to the machining conditions. And they should be seen in conjunction with the application of the "M" system parameters.

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