 ISSN: 2251-9246
EISSN: 2345-6221

pp. 9:15

Adaptive Control of Machining Process Using Electrical Discharging Method (EDM) Based on Self-Tuning Regulator (STR)

Seyed Mahyar Mehdizadeh Moghadam[1], Esmail Alibeiki [*1], Alireza Khosravi[2]

[1]Department of Electrical Engineering, Aliabad Katoul Branch, Islamic Azad University, Aliabad Katoul, Iran,
Mahyar.mehdizade67@yahoo.com, esmail_alibeiki@aliabadiau.ac.ir (Corresponding Author)
[2]Faculty of Computer and Electrical Engineering, Babol Noshirvani University of Technology, Babol, Iran, akhosravi@nit.ac.ir

Abstract

In order to improve the optimal performance of a machining process, a booster to improve the serve control system performance with high stability for EDM is needed. According to precise movement of machining process using electrical discharge (EMD), adaptive control is proposed as a major option for accuracy and performance improvement. This article is done to design adaptive controller based on self-tuning regulator (STR) using adaptive online detection methods of gradient MIT and normalized gradient MIT to adjust machine's movement time in the control process. Process performance after controller design shows that determined Gaps location at different points is appropriate and improves machining rates almost 100%.

Keywords: Self-Tune Control, Adaptive Control, EDM, MIT rule.
Article history: Received 19-FEB-2018; Revised 03-MAR-2018; Accepted 07-MAR-2018.

1. Introduction

Machining by electrical discharge method (EMD) is one of the special methods to milling that there is no direct contact between work piece and electrode, and therefore there is no physical force [1]. Hardness coefficient ratio of dwarf separation is related to work piece electrical conductivity no its hardness [2]. The basis of this method could be used for all electric current conductive material in machining process which has four different parts: 1.electrods, 2.workpiece 3.dielectric fluid 4.current source [3]. Using purpose of dielectric (water or oil) is temperature reduction in machining area and transfer machined particles from machining area so that suitable sparks occur and arc phenomenon does not occur [4]. If there be a potential difference between two electrodes (the work piece and the electrode), because of electrons high collision to dielectric between two electrodes, dielectric molecules will be ionized and a channel from ions between two electrons is created which is called plasma channel [4, 5]. Due to ion severe collisions to the work piece, milling is done. Sparking and on the other hand, tools advancing to the work piece (as back and forth vibration with high-frequency) tool shape is milled in work piece over time. Surface smoothness depends on produced spark. The stronger the spark the rougher the level, but machine speed will be more [6]. Commonly devices are Spark and Wierkat. Monitoring and EDM process control is often based on identification and adjustment of the machining location in the distance between the electrode and work piece during arc production process. Many efforts have been done to improve monitoring and system control to find gap location set up the machine in real time to keep the process in optimum conditions [7-8]. The main reason to use adaptive control for EDM process is that adaptive controller can correct its behavior in response to time variation of the parameters in the EDM process and noises characteristics. [9]. Control problems design in this article is a process model parameters determination and parameterization of controller coefficients. Continue, process model investigation and controller design of communication formulation between control variable u(t) and T(t) will be investigated.

2. Control Design Analysis for the EDM Process

Usually, an EDM machine uses an open-loop control scheme for EDM process. To access the adaptive controller, a closed-loop control design is needed [2]. One is a ratio to spark pulses transient electric arc pulses to all pulses, and the other is permanent arc pulse ratio small pulses to all pulses [10]. This article is paid to the second mode because control aim is to keep machining stable so will have more direct access to this aim. In addition, this method has more protection against damage caused by electrical arcs and short pulses. Giving this protection, y, which is gap situation identifier, could be shown by Eq.1 as:

$$y = \frac{(\tau_{stab.arc} + \tau_{short})}{(\tau_{spark} + \tau_{trans.arc} + \tau_{stab.arc} + \tau_{short})} \quad (1)$$

Where τ_{short}, $\tau_{stab.arc}$, $\tau_{trans.arc}$, τ_{spark} are shown short pulses, stable arcs, transient arcs, and number of sparks in a period, respectively. Prediction model which is extended in reference [11-12], can be used for gap situation new definition defined in this article. The adaptive control system is finding a method for EDM process and adjusting controller coefficients when EDM process characteristics and node parameters are changing.

3. Controller Design and Modeling

To calm machining noise, gaps situations are filtered after calculation in Eq.1. Pay attention that in continue all calculations and control functions investigation based on gap location are filtered. Identifying EDM process parameters, the process can be described as a pulsed transfer function and a filtered white noise that operates on the system [9, 13]. The process can be simplified as Eq. 2:

$$y(t) = \frac{B_1(q^{-1})}{A_1(q^{-1})} u(t) + \frac{1}{D_1(q^{-1})} e(t) \quad (2)$$

Which happens to be EDM process Model structure (Eq. 3).

$$G(q) = \frac{B(q)}{F(q)}, H(q) \frac{C(q)}{D(q)} \quad (3)$$

Where is backward shift operator, $q^{-1}u(t) = u(t-1)$and Consider the Eq.3, assume that$y(s)$, $u(s)$ are known for $s < (t-1)$, then after simple manipulations give the system model. (Eq.4)[11]:

$$\begin{aligned} B(q) &= b_1 q^{-1} .... b_{nb} q^{-nb} \\ C(q) &= 1 + c_1 q^{-1} .... c_{nc} q^{-nc} \\ D(q) &= d_1 q^{-1} .... d_{nd} q^{-nd} \\ F(q) &= f_1 q^{-1} .... f_{nf} q^{-nf} \end{aligned} \quad (4)$$

Where y is the adjustable parameter vector. The error between the prediction and the measured output is (Eq.5). Let (Eq.6a)

$$\varepsilon(t,\theta) = \frac{B(q)D(q)}{C(q)F(q)} u(t) + \left[1 - \frac{D(q)}{C(q)}\right] y(t) \quad (5)$$

$$w(t,\theta) = \frac{B(q)}{F(q)} u(t) \quad (a)$$
$$v(t,\theta) = y(t) - w(t,\theta) \quad (b) \quad (6)$$

Further collection gives the error (Eq.7):

$$v(t,\theta) = y(t) - \hat{y}(t,\theta) = \frac{D(q)}{C(q)} v(t,\theta) \quad (7)$$

Thus, define a state vector $q(t,\theta)$(Eq.8):

$$\begin{aligned} & v(t,\theta) = [u(t-1),....u(t-n_b,\theta), -w(t-1,\theta) \\ & ,....., -w(t-n_f,\theta), \varepsilon(t-1,\theta),....,\varepsilon(t-n_c,\theta), \\ & -v(t-1,\theta),.....,-v(t-n_d,\theta)]^T \end{aligned} \quad (8)$$

Let the adjustable parameter vector be (Eq.9):

$$\theta = [b_1....bn_b, f_1......fn_f, c_1......cn_c, d_1......dn_d]^T \quad (9)$$

Then in terms of Eqs. (6a) and (7), further collection gives (Eq.10):

$$\begin{aligned} & w(t,\theta) = b_1 u(t-1) + ... + bn_b u(t-n_b), \\ & - f_1 w(t-1,\theta) - ...., - fn_f w(t-n_f,\theta) \end{aligned} \quad (10)$$

$$\begin{aligned} & \varepsilon(t,\theta) = v(t,\theta) + d_1 v(t-1,\theta) + ... \\ & + dn_d v(t-n_d) - c_1 \varepsilon(t-1,\theta) - .... \\ & - cn_c(t-n_c,\theta) \end{aligned} \quad (11)$$

Insert Eq. (6b) into Eq. (11) and replace w (t, y) with Eq. (10). After collection it gives (Eq.12):

$$\varepsilon(t,\theta) = y(t) - \theta^T \varphi(t,\theta) \quad (12)$$

The selections of candidate models are performed on Matlab platform. Suppose that a set of candidate models has been selected and parameterized as a model structure using a parameter vector in Eq.9, then search for the best model within the set becomes the problem of how to determine or estimate y. Since each model represents a way of predicting the future output, the errors between the prediction and measured output are considered to be criterion for searching the best model. Then according to the error Eq.12, there is a scalar description [11]. This fact denotes that it is appropriate to use this model structure to recursively track gap state variations. The model is described as Eq.13:

$$y(t) = [B(q)/F(q)]u(t) + [C(q)/D(q)]e(t) \quad (13)$$

Where:
$B(q) = 0.02458q^{-1}$
$C(q) = 1 + 1.001q^{-1}$

$D(q) = 1-2.862q^{-1} + 2.788q^{-2}_{0.925q^{-3}}$
$F(q) = 1-1.707q^{-1} + 0.7594q^{-2}$

With respect to the identification parameters Eq.14 can be identified as:

$$y(t) = \frac{B_0(q^{-1})}{1+a_1(q^{-1})+a_2(q^{-2})}u(t) + \frac{1}{1+d_1(q^{-1})+d_2(q^{-2})+d_3(q^{-3})}e(t) \quad (14)$$

Where $y(t)$ is filtered gap location. Now process could be written as a standard form of Eq.15:

$$A(q)y(t) = B(q)u(t) + C(q)e(t) \quad (15)$$

Where $A(q)$ is assumed for a discrete system at time as Eq.16:

$$A(q) = A_1(q)D_1(q) = B_1(q)D_1(q)$$
$$C_1(q) = A_1(q)D_1(q) \quad (16)$$

Where in Eq.16, all polynomial zeros of inside circle are unit. The control strategy of minimum variance is used with Single-step prediction to design self-adjusting regulation by selecting the control signal [14-15]. Actually, predicted value follows desired value and after simplification, control signal can be written as Eq.17:

$$u(t) = \frac{C}{qB}y_r - \frac{C-A}{B}y(t) \quad (17)$$

Where y_r is determined gap location which must be followed Control block diagram is represented as Fig. 1 from Eq.13 and Eq.17. Signal transmission rate from the PC to the system is 0.5 seconds. In this case, programs consumed time to identify discharge pulses, estimate model parameters, calculate controller design, and sending rate will be considered 2 seconds. This time is considered as TD time changing [15-16].

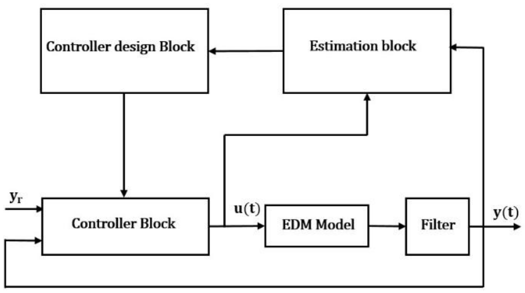


Fig. 1. Block diagram of a random STR controller in the presence of noise

Two inputs enter to controller block. One is determined gap location y_r and the other is filtered gap location. Each gap location comes from a discharge pulses rate in two seconds. Each gap location after identification by monitoring system is sent by a filter to reduce noise and then will be feed backed to the controller. Filtered gap location is used to calculate control variable $u(t)$ with estimated coefficients of A, B, C from estimate block and controller design block is shown in Fig (1). Power parameters are given in Table (1) and T_J parameters are given in Table (2) [11-17]:

Table.1.
Power Parameters

Power Parameters	***Considered Value***
	120
	30
	150
	5

Table.2.
Parameters of the tool jump setting

T_J *parameters*	*Considered value*
Amplitude	1.24mm
Speed	500 mm/min

In EDM process in reference [11], all inputs are combined with step input in the same way. The reason is system parameters setting in normal machining mode without feedback control [18]. In controlled EDM process modeling which uses feedback control as adaptively, since all inputs in machining except $T(t)$ remain unchanged, all inputs are combined with the variable $u(t)$. Although $u(t)$ is not a step input, but it is changed by gap modified locations respectively in control strategy of minimal variance to keep gap location to follow determined gap location y_r. It is necessary that when gap location becomes more than gap location reference y_r, $T(t)$ must be reduced to neutralize arc increscent and short pulses. It should be noted that it is seen from equation (2) that $u(t)$ is proportional to gap location. It also concludes that $u(t)$ is fit with $T(t)$ changing, that its discrete form is as Eq.18:

$$T(t) = T(t-1) + (T_{\max} - T_{\min})u(t)/K \quad (18)$$

Where k is an adjustment factor which is obtained through empirical experiments. As see, Eq.15 is a normalized form. Investigating real locations in machining, the maximum and minimum values are set to 2 and 0.25 seconds, respectively, and the initial value is 0.5 seconds [11-19]. Eq.11 and Eq.13 show that there are only 6 parameters that must be estimated. When a gap location was estimated in a head location, then parameters are investigated. Control variable of these estimated parameters is calculated in Eq.15 and $T(t)$ is adjusted according to Eq.16, therefore, $T(t)$ in gap location phrases of real-time are adapted to achieve a robust machining.

4. System Simulation and Analysis for Online Identification Methods

In input design of STR controller, the control signal is obtained from Eq.17. In Eq.17, y_r is gap desirable location and $y(t)$ is gap real location. Fig 3.2 and 4 illustrate our relation between gap location, the control signal, and $T(t)$ for k=10000, 100, 1000. Calculated T value is entered into the EDM process.

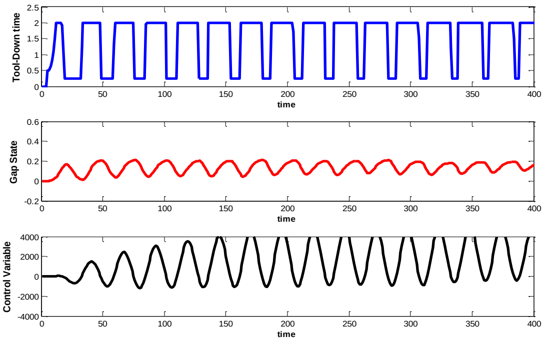


Fig. 2. STR controller effect on T (t) curves, control signal and gap location for K=100

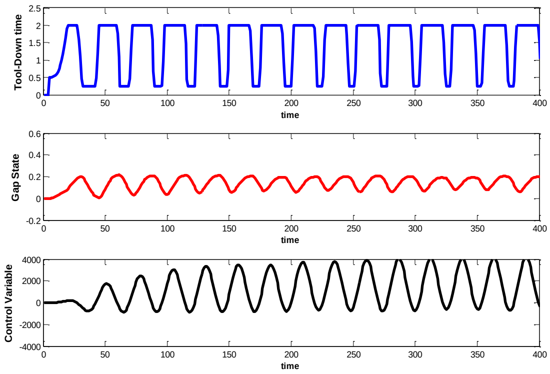


Fig. 3. STR controller effect on T (t) curves, control signal and gap location for K=1000

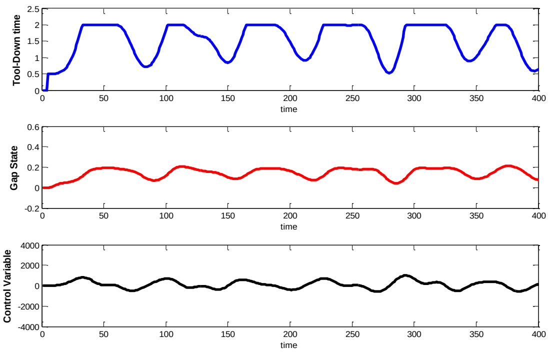


Fig. 4. STR controller effect on T (t) curves, control signal and gap location for K=10000

When k is small (k=100), in Fig2, control variable $u(t)$ and $T(t)$ are oscillate strongly and control system will be unstable. When k is more than an amount (k=1000) in Fig.3, oscillation will be less a bit, but control system is unstable yet. Increasing k in k=10000 as shown in Fig.4, time $T(t)$ won't have any oscillation and swing corresponding with gap location. Meanwhile, $T(t)$ in k=10000 is well suited to variable $u(t)$ Figs 2 and 4 show that whenever gap location farms from determined gap location, control variable will act to neutralize deviation and will try that gap location follow determined gap location. These Figs show that selecting k=10000 or more is suitable for the control system.

5. Controller Design and Adaptive Control Methods Simulation of Reference Model for EDM System

In this section, adaptive control design methods based on MIT rule and generalized MIT rule will be done on EDM system. Since these methods are used for continuous systems in time, at first discrete system must be continuous that continuous equivalence of EDM discrete system with no white noise and its dynamic is as Eq.19 [15].

$$G(s) = \frac{s^7 - 0.32s^6 - 11.68s^5 - 129.8s^4}{s^7 + 80.79s^6 + 24s^5 + 3.44s^4} \cdots \frac{-259s^3 - 9.23s^2 - 1.038s - 4.153e6}{2.012s^2 + 1.09e6s + 1.69e5} \quad (19)$$

As seen system degree is high and using reference model methods for up system will have lots of problems. To do this, we want to approximate system with less degree. We have 4 poles and 6 zeros far from the origin and close to each other that can easily be ignored. Regarding time response form, the system could be approximated by the first-order system in first-order form as: $G = \frac{K}{Ts+1}$. To obtain k according to final amount of step response, we have: $\lim y = Kt \xrightarrow{1} \infty$ and Time constant (T) when system step response reaches 0.63 of final amount is obtained from the Fig that is equal to 6.16 seconds. As a result, the convergence function of the approximate system is obtained as follows (Eq.20).

$$G = \frac{24.6}{6.16s + 1} \quad (20)$$

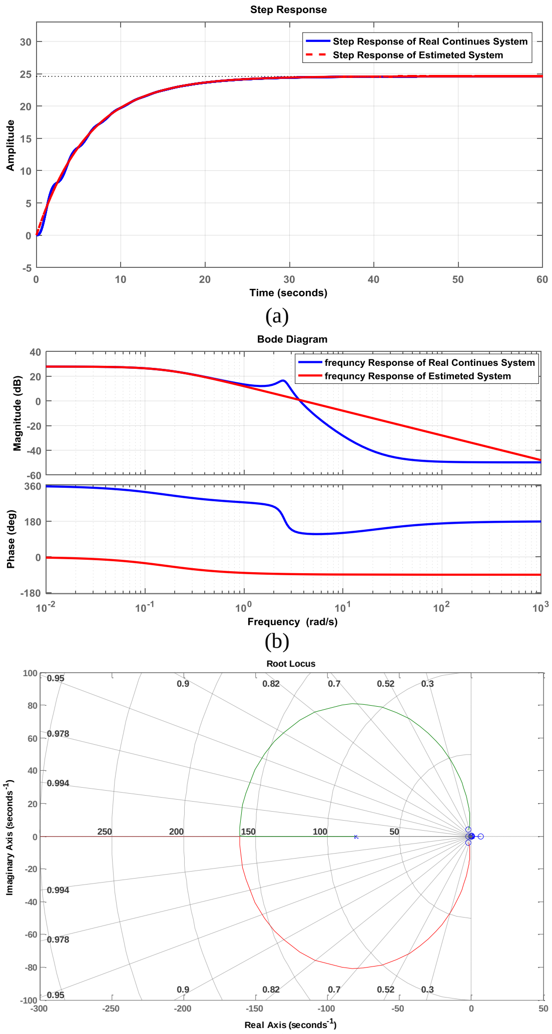
In Fig.5, step response and frequency response of the real system and approximated system are plotted. As shown in Fig 5, as shown in Fig 5, the approximated system has a very close response to the real system.

6. Adaptive Controller Design Based on MIT Rule

Definition error as the difference between system output and reference system output, the cost function is defined as error square. System parameters must be changed as the cost function is minimized. Therefore, parameters must be changed in direction of negative cost function gradient. Eq.21 is used to change parameters in time [20-21].

$$d\alpha / dt = -\gamma e \partial e / \partial \alpha \tag{21}$$

Assuming that the control signal is linear combination reference input and system output that controls signal coefficient is equal to α1 than reference input and is $-\alpha_2$ than output, optimal values for these parameters will be $\alpha_1 = 0.5, \alpha_2 = 0.460$. If controller parameters reach the optimal values, the fault will be minimized. Of course, in reference model control, the aim is not parameters convergence but system behavior tendency to desirable model is important. Calculating cost function as fault square in terms of output and control signal, and replacing the control signal with equation $u = \alpha_1 u_c - \alpha_2 y$ and placement, derivatives calculation and simplifying, intended equation to correct parameters to reduce fault square gradient will be like Eq.22.

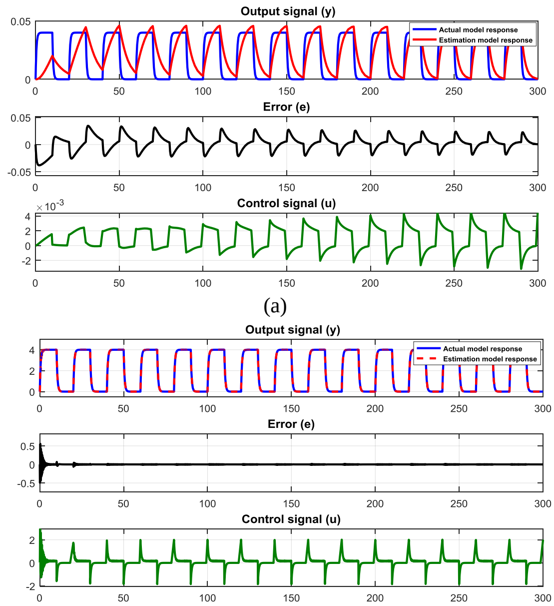


(a)

(b)

(c)

Fig. 5. System step response of continuously in time (a) real EDM (b) frequency response and root locus(c)



(a)

(b)

Fig. 6. Output time response, fault amount and control energy for gain 3 and square input domain (a) 0.02 and (b) 2 based on MIT method.

$$\frac{d\alpha}{dt} = \begin{bmatrix} \frac{d\alpha_1}{dt} \\ \frac{d\alpha_2}{dt} \end{bmatrix} = -\gamma \times \left(\frac{a_m}{s + a_m}\right) \times \begin{bmatrix} u_c \\ y \end{bmatrix} \times e \tag{22}$$

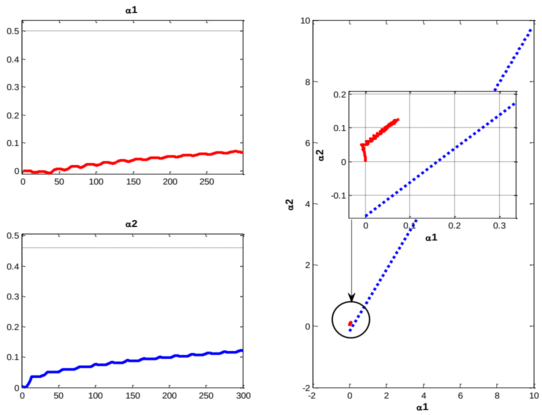
For two-step inputs $y_r = 0.02, 2$ and pulse input, system output (gap location) estimated output signal domain is shown in Fig 6 for square input with domain 0.02 and 2.

As seen in Fig 6, parameters do not converge to their optimal value in (a) for the square input 0.02 and output cannot follow the reference model. But in Fig 6 (b), it is seen that with increasing in reference input signal dominant, parameters converged to desire value and output could follow reference model and Ideal behavior of the control parameters for the correct position of the EDM machine for the step input of 0.5 for and as well as the positioning accuracy of the chip distance for the cropping Fig 7(a) 0.02 and Fig 7(b)2 based on the MIT method.

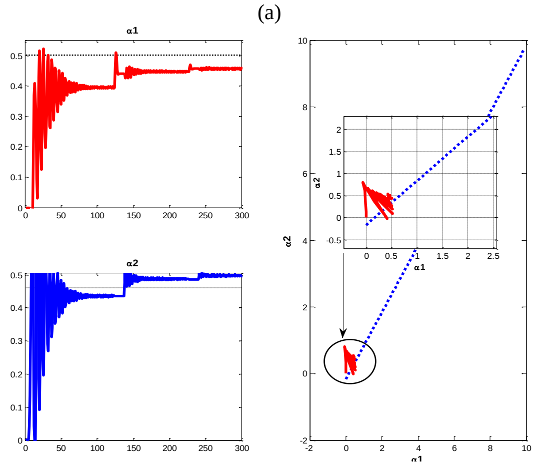
The control signal (u) has a mutation in output change points for Fig 6 (b). In MIT method, input domain and y are effective in system response, so normalized gradient method will be investigated to have comparative behavior and analysis of adaptive methods. The normalized method is used to reduce input signal amplitude effect and y on system response. Parameters setting relation in this method is expressed as Eq.23:

$$d\alpha / dt = -\gamma / (\theta + \vartheta^T \vartheta) \times e\theta > 0$$

$$\vartheta = \frac{-\vartheta e}{\vartheta \alpha} \tag{23}$$



(a)



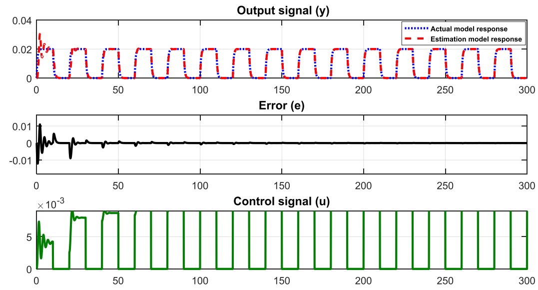
(b)

Fig. 7. Ideal behavior of the control parameters for the correct position of the EDM machine for the step input of 0.5 for as well as the positioning accuracy of the chip distance for the cropping (a)0.02 and (b)2 based on the MIT method.

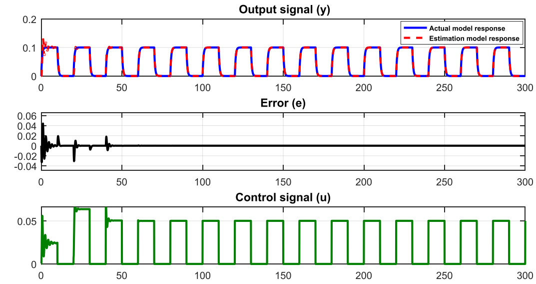
Considering control signal as $u = \alpha_1 u_c - \alpha_2 y$ and calculate fault square (cost function) and replace control signal in Eq.24, parameters correction expression is as:

$$d\alpha / dt = -\gamma \times \frac{b_m}{s + a_m} \times \frac{1}{\alpha + \frac{b_m^2}{(s + a_m)}(u_c^2 + y^2)} \times \begin{bmatrix} u_c \\ y \end{bmatrix} \times e \tag{24}$$

For two-step inputs and pulse input, system output (gap location) is shown in Fig 7. As seen in Fig 8, parameters are converged and output trace reference model for Fig 8(a) and 8(b). In this mode fault for signal amplitude, 0.02 for normalized gradient method is very small. However, in the normalized method, the effect of input signal amplitude and y on response becomes less but this method does not change closed-loop stability. Fig 9(a) and 9(b) shows the behavior of the desired values in versus with respect to the step input.

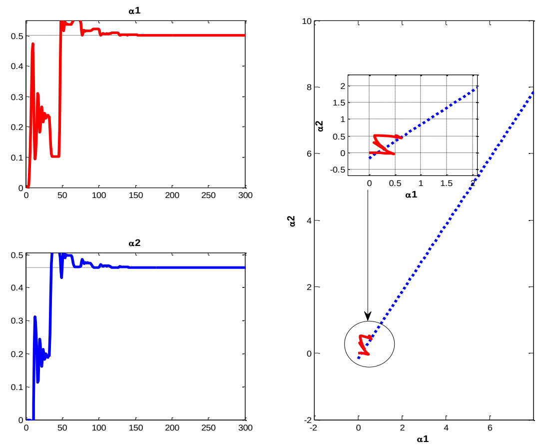


(a)

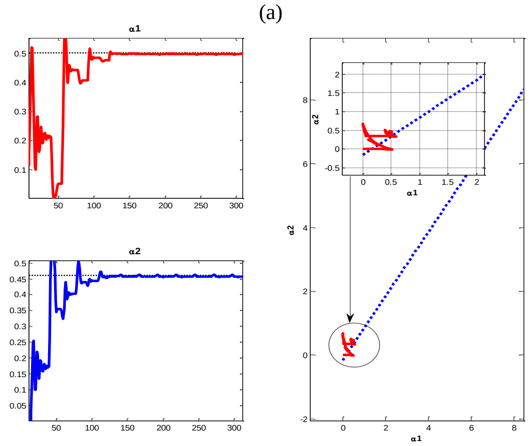


(b)

Fig. 8. Output time response, fault value and control energy for gain (a) 5 and (b) 2 and input signal domain of square wave is equal to (a) 0.02 and (b)2 based on MIT normalized gradient.



(a)



(b)

Fig. 9. Ideal behavior of the control parameters for the correct position of the EDM machine for the step input of 0.5 for as well as the positioning accuracy of the chip distance for the cropping (a)0.02 and (b)2 based on the MIT Normalized method.

7. Conclusion

According to precise movement of the machining process using electrical discharge, the identification method is proposed to an important option online method to increase accuracy and improve milling operation. Control operations for self-tuning references (STR) method based on MIT and normalized MIT are implemented. simulation results show that in MIT method, when adaptive gain increases, parameters convergence speed increases, too and increasing in input domain causes increasing in tracing fault, but in normalized MIT method when adaptive gain increases, convergence speed improves and by increasing in input signal domain, there is no oscillatory behaviour in estimated parameters output and tracing fault will be negligible and acceptable control energy for the system will be produced.

Reference

[1] D. Ethz, D.F. Dauw, "About the application of fuzzy controllers in high- performance die-sinking EDM machines", Proceedings of the 11th International Symposium for Electromachining, CIRP, 1995

[2] W.M. Wang, K.P. Rajurkar, "Adaptive control of WEDM by on-line identifying workpiece height", Transactions of the North American Manufacturing Research Institution of SME, 1994.

[3] K.-M. Tsai, P.-J. Wang, "Comparisons of neural network models on material removal rate in electrical discharge machining", Journal of Materials Proces- sing Technology 17 ,2001.

[4] K.-M. Tsai, P.-J. Wang, "Predictions on surface finish in electrical discharge machining based upon neural network models", International Journal of Machine Tools and Manufacture 41 ,2001 .

[5] K. Wang, H.L. Gelgele, Y. Wang, Q. Yuan, M. Fang, "A hybrid intelligent method for modeling the EDM process", International Journal of Machine Tools and Manufacture 43 ,2003.

[6] D.K. Panda, R.K. Bhoi, "Artificial neural network prediction of material removal rate in electro discharge machining", Materials and Manufacturing Processes 20 , 2005.

[7] A. Yahya, C.D. Manning, "Determination of material removal rate of an electro- discharge machine using dimensional analysis", Journal of Physics D: Applied Physics 37 , 2004.

[8] G. Petropoulos, N.M. Vaxevanidis, C. Pandazaras, "Modeling of surface finish in electro-discharge machining based upon statistical multi-parameter analysis", Journal of Materials Processing Technology ,2004.

[9] R. Snoeys, F. Staelens, D. Dauw, "Adaptive control optimization as basis for intelligent EDM die sinking machines", Advances in Non-Traditional Machin- ing, ASME PED, New York, vol. 22.2012.

[10] K.P. Rajurkar, W.M. Wang, "A new model reference adaptive control of EDM", Annals of the CIRP, vol.38 , no.1 ,1989.

[11] M. Zhou, et al., "A time-varied predictive model for EDM process", International Journal of Machine Tools and Manufacture, 2008.

[12] Norliana Mohd AbbasDarius G.SolomonMd.Fuad Bahari, "A review on current research trends in electrical discharge machining (EDM)", International Journal of Machine Tools and Manufacture, Vol- 47, Issu- 7–8, 2007

[13] R. Snoeys, D. Dauw, J.P. Kruth, Improved adaptive control system for EDM process, Annals of the CIRP, ,vol.29 , no.1, 1980.

[14] W.M. Wang, K.P. Rajurkar, "Digital gap monitor and adaptive integral control for auto-jumping in EDM", Journal of Engineering for industry – Transactions of the ASME, 1995.

[15] V. Marroccor, F. ModicaI. FassiG. Bianchi, "Energetic consumption modeling of micro-EDM process", The International Journal of Advanced Manufacturing Technology, vol.93, no.8, 2017.

[16] K.P. Rajurkar, W.M. Wang, "Real time stochastic model and control of EDM", Annals of the CIRP ,vol.39 , no.1, 1990.

[17] K.P. Rajurkar, W.M. Wang, "Improvement of EDM performance with advanced monitoring and control systems", Journal of Manufacturing Science and Engineering- Transaction of the ASME 119, 1997.

[18] A.Y. Allidina, F.M. Hughes, "Self-tuning controller with integral action", Optimal Control Applications and Methods 3 ,1982.

[19] M. Boccadoro, D.F. Dauw, "About the application of fuzzy controllers in high- performance die-sinking EDM machines", Annals of the CIRP ,vol.44 , no.1 ,1995.

[20] M. S. Ehsani, "Adaptive Control of Servo Motor by MRAC Method", Vehicle Power and Propulsion Conference, 2007.

[21] T. Rehm, P. Schmidt, "Intelligent model reference adaptive control applied to motion control", Thirtieth IAS Annual Meeting, IAS '95 IEEE, 1995.

ISSN: 2251-9246
EISSN: 2345-6221