DIFFERENTIAL EVOLUTION FOR OPTIMIZATION OF PID GAIN IN ELECTRICAL DISCHARGE MACHINING CONTROL SYSTEM

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ABSTRACT

PID controller of servo control system maintains the gap between Electrode and workpiece in Electrical Discharge Machining (EDM). Capability of the controller is significant since machining process is a stochastic phenomenon and physical behaviour of the discharge is unpredictable. Therefore, a Proportional Integral Derivative (PID) controller using Differential Evolution (DE) algorithm is designed and applied to an EDM servo actuator system in order to find suitable gain parameters. Simulation results verify the capabilities and effectiveness of the DE algorithm to search the best configuration of PID gain to maintain the electrode position.

Keywords: servo control system; electrical discharge machining; proportional integral derivative; controller tuning; differential evolution.

ÉVOLUTION DIFFÉRENTIELLE POUR L'OPTIMISATION DE GAIN D'UN DÉRIVÉ PROPORTIONNEL INTÉGRAL (PID) DANS UN SYSTÈME DE COMMANDE D'ÉLECTRO-ÉROSION PAR DÉCHARGE ÉLECTRIQUE

RÉSUMÉ

Le dispositif de commande dérivée proportionnelle intégrale (PID) d'un système servomoteur maintient l'espace entre l'électrode et la pièce à usiner par électroérosion (EDM). La capacité du dispositif de commande est importante car ce procédé d'usinage est un phénomène stochastique, et le comportement physique de la décharge est imprévisible. Par conséquent, un dispositif de commande dérivée proportionnelle intégrale (PID), utilisant un algorithme à évolution différentielle (ED) est conçu et appliqué au système d'électroérosion par décharge électrique (EDM) afin de trouver les paramètres de gain appropriés. Les résultats de simulation ont permis de vérifier les capacités de l'algorithme à évolution différentielle pour trouver la meilleure configuration du dispositif de commande dérivée proportionnelle (PID) pour maintenir la position de l'électrode.

Mots-clés : système d'asservissement ; d'usinage par étincelage ; proportionnelle intégrale dérivée ; optimisation du régulateur ; évolution différentielle.

1. INTRODUCTION

PID controller is the most popular ones on dealing with industrial control processes. It is reliable in operation, robust in performances and up to 90% of all control strategies are PID. Various applications have implemented using this PID controller, such as process control, motor drives, automotive, flight control [1]. On the contrary, determination of optimal configuration parameters for PID constants is very challenging. It has been experimentally checked that more than 30% of the installed controllers are operating in manual mode and 65% of the automatic close loops are operated in poorly tuned condition [2], so new approaches algorithm to adjust PID gain controller are very important.

Tuning methods of PID parameters are classified into traditional and intelligent methods. Conventional methods such as Zigler–Nichols [3] and simplex methods are not simple and difficult to be implemented in digital system. Using these conventional methods, system response produces surge and big overshoot. Recently, intelligent approaches such as genetic algorithm, particle swarm optimization have been proposed for PID optimization. Among them, genetic algorithm (GA) has a significant contribution and has been applied successfully to solve many problems of optimal PID controller parameters. In the past decades, different tuning methodologies of PI and PID controllers have been proposed in literatures such as auto tuning, self-tuning and computational intelligence [1, 4, 5].

Many researchers have tried to propose a new algorithm or strategy in order to obtain a good technique to determine gain parameters in PID controller. Conventional or traditional methods called Zigler–Nichols try to find a suitable PID constants configuration based on step response analysis [6], so the accuracy of capturing the step response graph is significantly contributed to the determination of PID parameters. Artificial Intelligence algorithm tries to find optimum parameter in PID controller based on fitness function. During the training step, the parameters will be updated until the system response has fulfilled the objective function requirement.

Unfortunately, it is not easy to find a proper configuration gains of PID controllers because many industrial plants are often burdened with problems such as high order, time delays, poorly damped, nonlinearities and time-varying dynamics. Over the years, several authors have proposed the tuning of PID to control variable processes by optimization methods, such as genetic algorithms [7–13], particle swarm optimization [14, 15], tribes algorithm [16], harmony search [17, 18], evolution strategy [19], ant colony [20]. Moreover in [21] other artificial intelligence technique called fuzzy is used as an active suspension system controller using fuzzy-skyhook control theory, which offers new opportunities for the improvement of vehicle ride performance. Meanwhile, sliding mode control as an alternative way to design an optimal control is applied to spherical robot [22]. In this paper, Differential Evolution as a new Evolutionary Algorithm is used as a tool for solving the class of multi objective optimization problems that results from a PID design problem for maintaining the gap between electrode and workpiece in EDM system process. The fitness function which is called Integral Absolute Error (IAE) is chosen to obtain an automatic method for designing single-loop PID controllers.

2. SYSTEM DESCRIPTION

Electrical Discharge Machining (EDM) is a controlled metal removal process that is used to remove metal by means of electric spark erosion [23, 24]. The English scientist Priestley first reported the erosive effect of electrical discharges in 1770. In this process, an electrical spark is used as the eroding tool to erode the workpiece to produce a finished part (mould). The metal removal process is performed by applying an electrical discharge of pulsed high frequency direct current through the electrode to the workpiece. The electrode location is controlled by the machine and is positioned so as not to contact the workpiece. A precise controlled space is maintained, allowing the spark to discharge its current from the electrode to

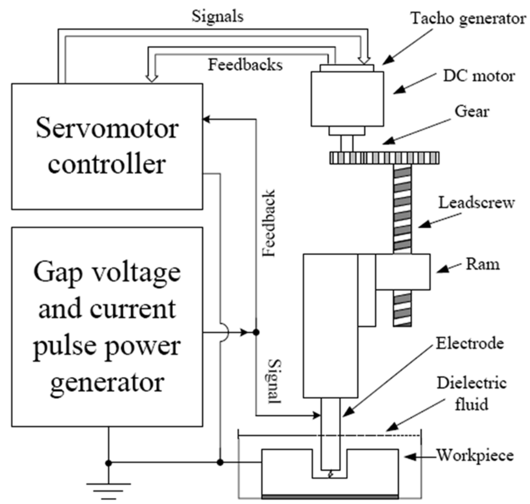

Fig. 1. Basic elements of an EDM system [23].

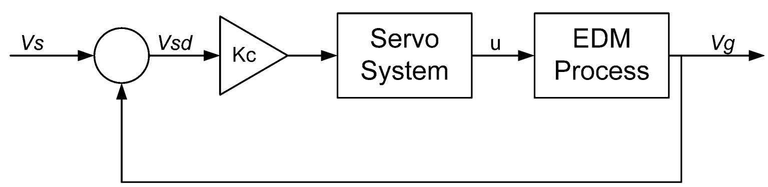

Fig. 2. Block diagram of an existing EDM servo control system.

the workpiece through an insulated dielectric fluid. This removes tiny particles of metal, called debris, from the workpiece.

Figure 1 shows basic elements of the EDM system. When the gap between the electrode and workpiece is sufficiently small (10–50 μm), said gap being controlled by the position control servo system, an electrical spark occurs in the gap. In this process, which is also known as a discharge, current is converted into heat [25, 26]. The surface of the material is very strongly heated in the area of the discharge channel. If the flow of current is interrupted, the discharge channel collapses very quickly. Consequently the molten metal on the surface of the material evaporates explosively and takes liquid material with it down to a certain depth. Then a small crater is formed. If the process which is started from movement of electrode downward to workpiece until a small crater is formed is followed by another, new craters are formed next to the previous ones and the workpiece surface is constantly eroded.

3. GAP CONTROL IN EDM SYSTEM

Machining gap is adjusted using ram servo control system at a critical distance for the continuous occurrence of electric discharge. In the same EDM power generator settings, the machining stability and productivity depend on the performance of this servo control mechanism. Figure 2 shows the block diagram of a EDM servo control unit.

In general, there are three components which construct the EDM servo control system. K_c is applied at the controller block. The servo system block consists of dc motor model and its accessories including ram and leadscrew. EDM process is a model for EDM discharge phenomenon. At this model, gap between electrode and workpiece is converted to voltage which represents voltage drop occurred during discharge state. This control system takes only the average gap voltage (V_g) as a feedback signal and then comparing

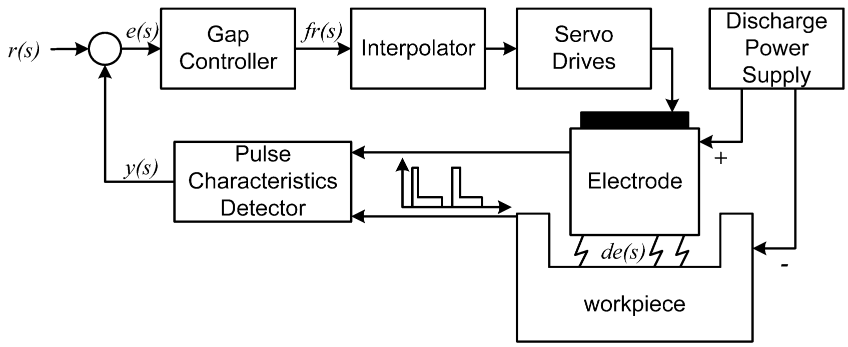

Fig. 3. Practical gap control system of an EDM [27].

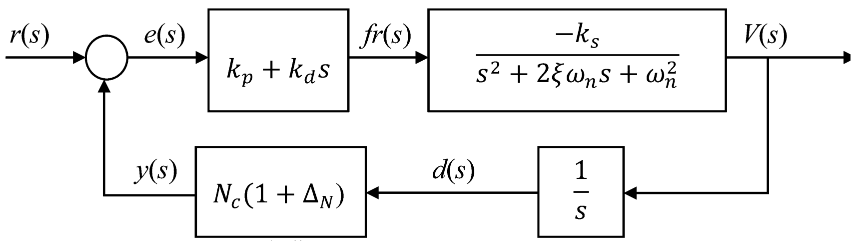

Fig. 4. Block diagram of the EDM gap control system [27].

it with a servo reference voltage (V_s). The differences between V_g and V_s, known as error, is fed to amplifier K_c, denoted by V_{sd}, drives the servo ram to adjust the gap distance so as to keep V_g at a level determined by V_s. The feedback signal contains the information relating to gap impedance but does not include details about gap state parameters such as normal sparking, harmful arcing, etc. The control gain K_c and the level of V_s are manually preset according to the operator's experiences. It has been noted that the conventional servo system does not effectively respond to either gap state parameters or process dynamic and stochastic features [27]. With this type of control system, therefore, the machining process is not optimal.

Figure 3 shows a practical gap control system of EDM process. The dynamic relationship between the feed rate $f_r(s)$ and the speed $V(s)$ can be expressed as

$$V(s) = \frac{-k_s}{s^2 + 2\xi\omega_n s + \omega_n^2}, \tag{1}$$

where k_s is a magnification constant. The terms ξ and ω_n is damping ratio and natural frequency of the servo system.

According to the foregoing analysis, the system is a type 1 system when the gap controller $y(s)$ is a pure proportional controller. A Proportional Derivative (PD) controller is applied to the system to improve the transient responses. Accordingly, $f_r(s)$ can be expressed as

$$F_r(s) = K_p e(s) + K_d s e(s). \tag{2}$$

Figure 4 shows the complete block diagram.

4. DIFFERENTIAL EVOLUTION (DE)

Differential Evolution (DE) can be used in optimization problems and a variant of evolutionary computation algorithm [28]. This algorithm is similar to Genetic Algorithm (GA) and Particle Swarm Optimization

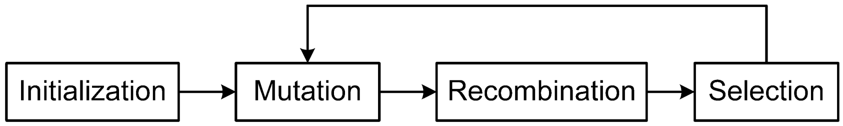

Fig. 5. Flow graph of differential evolution algorithm.

(PSO) but DE has some advantages. In general, DE has three main advantages (1) able to locate the accurate global optimum irrespective of the initial parameter values (2) has rapid convergence (3) utilizes few control parameters, thus easy and simple to use. During optimization step, crossover/recombination, mutation and selection operators are involve in this computation. Initially, population is given randomly. DE utilize mutation operator as a search mechanism and selection operation to search directly based on prospective regions on search space. DE algorithm is applied based on several steps. Figure 5 shows the flow graph of DE algorithm.

4.1. Initialization

Suppose a function with D real parameters will be optimized. The size of population, N, must be determined to be at least $N = 4$. Parameter vectors as a candidate solution to multidimensional optimization problems have the form $X_{i,G} = [X_{1,i,G}, [X_{2,i,G}, \dots, [X_{j,i,G}, \dots, [X_{D,i,G}]$, where $I = 1, 2, \dots, N$ and G is the generation number. The initial value for each candidate is uniform randomly selected in the interval $[X_L, X_H]$, where $XL = [X_{1,L}, X_{2,L}, \dots, X_{D,L}]$ and $X_H = [X_{1,H}, X_{2,H}, \dots, X_{D,H}]$ are the lower and upper bound of search space, respectively:

$$X_{j,i,0} = X_L + \text{ rand } [0,1](X_H - X_L). \tag{3}$$

4.2. Mutation

When a given parameter vector $X_{i,G}$, three vectors $(X_{r1,G}, X_{r2,G}, X_{r3,G})$ are randomly chosen in the range $[1,\ NP]$, such that indices i, $r1$, $r2$ and $r3$ are different. A donor vector $V_{i,G}$ is proposed by adding weighted difference between two vectors to the third (called base) vector as

$$V_{i,G} = X_{r1,G} + F(X_{r2,G} - X_{r3,G}), \tag{4}$$

where F is a mutation scaling factor, which is typically chosen from the range $[0,1]$.

4.3. Recombination

Donor vector $V_{i,G+1}$ and target vector $X_{i,G}$ are mixed to get a trial vector

$$U_{i,G} = [U_{1i,G}, U_{2i,G}, \dots, U_{ji,G}, \dots, U_{Di,G}]. \tag{5}$$

In this paper, a binomial recombination is applied. The recombination is defined as

$$U_{ji,G} = \begin{cases} V_{j,i,G}, & \text{if rand} \le CR \text{ or } j = j_{\text{rand}} \\ X_{j,i,G}, & \text{otherwise} \end{cases} \tag{6}$$

where $J = 1, 2, \dots, D$ and $I = 1, 2, \dots, N$. CR is known as a crossover rate and has a function to control parameter alternative of DE similar to F. $j_{\text{rand}} \in [1, 2, \dots, D]$ is randomly selected index to ensure that $U_{i,G}$ attains at least one element from $V_{i,G}$.

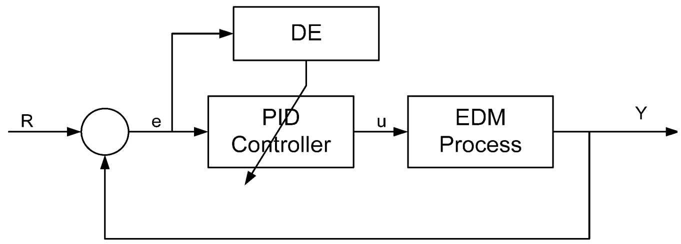

Fig. 6. DE-PID controller block diagram.

4.4. Selection

In order to realize the selection operators, Eq. (7) is defined as

$$X_{i,G+1} = \begin{cases} U_{i,G}, & \text{if } J(U_{i,G}) < (X_{i,G}) \\ X_{i,G}, & \text{otherwise} \end{cases} \tag{7}$$

$J(X)$ is the fitness function which will be optimized. In this work, the fitness function is Integral absolute error so $J(X)$ must be minimized. Thus, if a new trial vector select a lower value of the fitness function, it swaps the corresponding target vector in the next generation; otherwise the vector target is still at the same value. Hence, population will get better performance or still remains as a previous fitness value.

5. IMPLEMENTATION OF DE-PID CONTROLLER

Contribution of this paper is to apply the DE method in order to search an optimize configuration of PID gains controller of EDM Die-Sinking. A new control system optimization called DE-PID control system is proposed. Figure 6 shows the proposed controller block diagram.

The Differential Evolution (DE) algorithm is a promising new optimization technique which will be used to search an optimize parameters value in PID controller. At the first process, EDM model is controlled by initial PID parameter value. As stated before, Integral Absolute Error (IAE) will be used as a fitness function. Once the IAE is computed by Simulink software, it can be used as an Objective target value in the Differential Evolution (DE) algorithm. The DE will compute a new population based on this IAE value. In this work, DE is applied using matlab m.files coding. DE will propose a new population and then will be use as a new PID parameters value for the next generation.

The PID control algorithm involves three separate parameters, they are proportional gain K_p, integral gain K_i and derivative gain K_d. The mathematical description of the PID controller is shown as

$$u(t_i) = K_p.e(t_i) + K_i.\sum_{j=0}^{t_i} e(t_j)\tau_s + K_d.\frac{e(t_i) - e(t_{i-1})}{\tau_s}. \tag{8}$$

The objective function which is used to optimize the PID parameter is

$$J = \frac{1}{n+1}\sum_{i=0}^{n} |e(t_i)|, \tag{9}$$

where

$$e(t_i) = r(t_i) - x(t_i). \tag{10}$$

$r(i)$ and $x(i)$ present the reference input and observed output responses. A DE algorithm is proposed to adjust three parameters, K_p, K_i and K_d, iteratively and repeatedly until they reach optimal values and the control system achieves a satisfactory performance or stopping at a certain condition.

Table 1. Experimental results for P, PI, PID and PD controller.

No	K_p		K_i		K_d		IAE	
	PSO	DE	PSO	DE	PSO	DE	PSO	DE
1	26.4857	26.3956	–	–	–	–	0.8359	0.6059
2	26.2922	26.3228	0.3162	0.1808	–	–	0.8351	0.6057
3	20.5288	20.1720	0.1216	0.1262	–0.4600	–0.4657	0.8784	0.5884
4	18.9486	20.2434	–	–	–0.5056	–0.4618	0.8711	0.5893

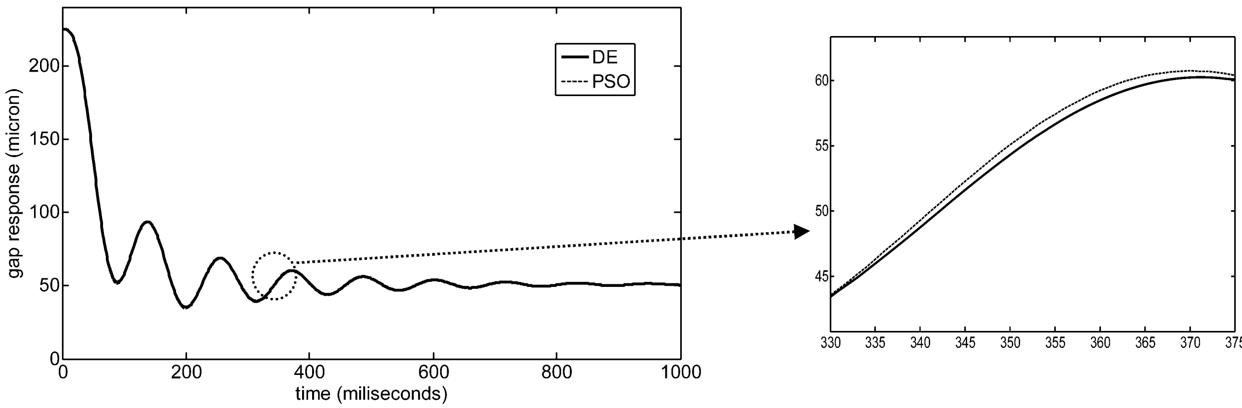

Fig. 7. DE-PID and PSO-PID response graph.

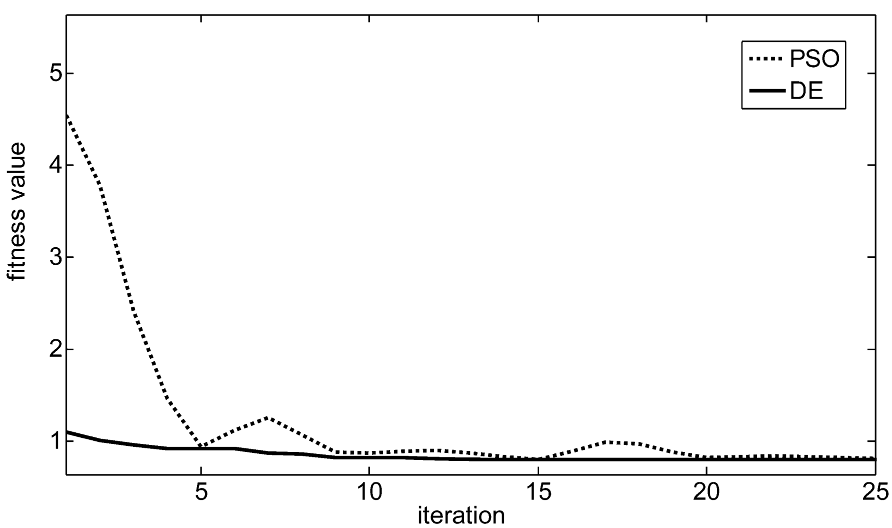

Fig. 8. Learning convergence of fitness value.

6. SIMULATION RESULTS

Simulation is conducted for several combinations. PID is configured to construct four types of controller, i.e., P, PI, PID and PD controller. Each controller is tuned by Differential Evolution (DE) and Particle Swarm Optimization (PSO). The results can be seen in Table 1.

Table 1 reveals gain value of each PID parameter for four types of controller combination. These values are achieved automatically using DE and PSO algorithm. The table shows DE optimization gives a better IAE value than PSO algorithm. PID controller using DE has the lowest IAE value at 0.5884.

Figure 7 shows a gap response graph for the PID controller which is tuned by DE and PSO. The initial position for the electrode is 225 micron and the target is 50 micron. It can be seen that DE and PSO give a similar response graph. There are small differences between the two response graphs, as shown in the enlarged graph in Fig. 7. Both optimization methods successfully find optimum gain parameters for the PID controller.

Figure 8 shows learning convergence of fitness value for DE and PSO optimization. The figure depicts 25 iterations. At first iteration, both algorithm compute fitness function using initial value for each PID gain parameter. DE and PSO try to find an optimum value for K_p, K_i and K_d during its searching process. PSO gives more fluctuates fitness value comparing to DE. The figure also shows that fitness objective function output from DE optimization which uses IAE is smaller. The figure also shows that DE gives better result in term of fast convergence. Therefore, less time is required when DE is applied to tune the PID gain.

7. CONCLUSION

In this paper, the PID controller parameters have been tuned by two artificial intelligence methods. This paper compares DE as an alternative algorithm to particle swarm optimization to show the advantages of DE. The simulation results reveal that determination of each parameter (K_p, K_i and K_d) is achieved automatically. Gap between electrode and workpiece can be maintained satisfactory. Differential Evolution and Particle Swarm Optimization successfully tune all combination of P, I and D parameters. The response of all combination of PID shows that the optimum gap can be achieved. However every combination has different response to reach the setting value. PID controller tuned by DE shows the best performance to reach the setting parameter with minimum fitness function value. In addition, the tuned PID controller using DE has resulted less processing time.

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