ARTICLE IN PRESS

Engineering Science and Technology, an International Journal xxx (2016) xxx–xxx

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Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: www.elsevier.com/locate/jestch

Full Length Article

Selection of parameters for advanced machining processes using firefly algorithm

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ARTICLE INFO

Article history:
Received 19 January 2016
Revised 12 May 2016
Accepted 5 June 2016
Available online xxxx

Keywords:
Firefly algorithm
Electrical discharge machining
Abrasive water jet machining
Optimization

ABSTRACT

Advanced machining processes (AMPs) are widely utilized in industries for machining complex geometries and intricate profiles. In this paper, two significant processes such as electric discharge machining (EDM) and abrasive water jet machining (AWJM) are considered to get the optimum values of responses for the given range of process parameters. The firefly algorithm (FA) is attempted to the considered processes to obtain optimized parameters and the results obtained are compared with the results given by previous researchers. The variation of process parameters with respect to the responses are plotted to confirm the optimum results obtained using FA. In EDM process, the performance parameter "*MRR*" is increased from 159.70 gm/min to 181.6723 gm/min, while "*Ra*" and "*REWR*" are decreased from 6.21 µm to 3.6767 µm and 6.21% to 6.324×10^{-5}% respectively. In AWJM process, the value of the "*kerf*" and "*Ra*" are decreased from 0.858 mm to 0.3704 mm and 5.41 mm to 4.443 mm respectively. In both the processes, the obtained results show a significant improvement in the responses.

1. Introduction

Advanced machining processes (AMPs) are believed to be one of the utmost developing progressive methods used in manufacturing industries. Materials processing with high precision are in demands of the present days, therefore, their study led to the evolution of difficult-to-machine, ultimate strength, temperature and corrosion resistant materials with other qualities. Machining of these materials with the use of conventional machining processes increase the machining time with high utilization of energy and cost [1–3]. Therefore, AMPs are widely used in most of the manufacturing industries. For the successful application of these processes, it is utmost required to have the ideal combination of parameters to enhance the performances.

Few researchers have investigated the effects of the process parameters on the electric discharge machining (EDM) and abrasive water jet machining (AWJM) performances. While considering the past researcher's work, experimental investigations were conducted on an EDM process to study the effects of machining parameters on surface roughness (*Ra*) [1]. Modeling and analysis have been attempted using response surface methodology (RSM) for EDM job surface integrity to determine the effects of the machining parameters [2]. Optimization of the performance characteristics, like material removal rate (*MRR*) and Ra in EDM process using the simulated annealing (SA) algorithm have been attempted by Yang et al. [3]. The effect of electrical parameters such as "pulse shape" and "discharge energy" on EDM performance characteristics have also been reviewed [4]. Experiments were conducted on EDM process with material such as aluminium metal matrix composite material and EN-31 tool steel to obtain the substantial effects of the process parameters (i.e., "pulse on time", "pulse off time", "discharge current" and "voltage") on the performance characteristics [5,6]. Analysis of variance (ANOVA) has been applied for determining the contribution of the process parameters [5]. An optimization technique "continuous ant colony optimization (CACO)" has applied to obtain the best parameter setting for *MRR* and *Ra* [7]. A fabrication of aluminium material matrix composites using EDM has been carried out by adding the aluminium powder in kerosene dielectric to enhance the output characteristics of the considered process [8]. An experiment has been conducted on EDM to determine the significant effects of "discharge current", "pulse on time", "tool lift time" and "tool work time" parameters on surface integrity [9]. The effects of various process parameters, i.e., discharge current, surfactant concentration and powder concentration on the performance characteristics using Taguchi methodology were reported by Kolli and Kumar [10]. A combination of Taguchi methodology and Technique for order of preference by similarity to ideal solution (TOPSIS) approach have been applied to determine the optimum and significant effects of the process

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Peer review under responsibility of Karabuk University.

http://dx.doi.org/10.1016/j.jestch.2016.06.001
2215-0986/

parameters on performance characteristics of the powder mixed EDM process [11].

A study of the characteristics of AWJM process has been carried out on epoxy composite laminates considering *Ra* and *kerf taper ratio* as performance parameters [12]. A numerical simulation work on AWJM process has been proposed with the simulation results between its process parameters and the cutting depth [13]. Integrated SA and genetic algorithm (GA) has been attempted for the optimization of AWJM process considered *Ra* as a performance parameter [14]; another work was reported for the estimation of *Ra* in the AWJM using integrated ANN-SA algorithm to have optimal AWJM parameters [15]. An experimental work has been reported on AWJM cutting process to cut the material AA5083-H32 and determined the best setting for "water jet traverse rate", "pressure", "abrasive flow rate" and "standoff distance" parameters [16]. The effects of process parameters such as "water pressure", "jet feed speed", "abrasive mass flow rate", "surface speed" and "nozzle tilted angle" on the responses "*MRR*" and "*Ra*" were reported and the sequential based approximation optimization technique have been used to obtain the optimum values of considered process parameters [17]. Several cutting processes have been applied to cut AA6061 material to investigate the variation in microstructure and hardness of the material [18].

The firefly algorithm (FA) with chaos, a meta-heuristic optimization algorithm, which simulates the fireflies based on the flashing and attraction characteristics of fireflies is described by Gandomi et al. [19]. Fister et al. [20] reviewed applications of FA and observed that many problems from different areas, like image processing, wireless sensor networks, antenna design, industrial optimization semantic web, chemistry, civil engineering and business optimization, robotics have been successfully attempted. A hybridization of ant colony optimization (ACO) with FA for unconstrained optimization problems have been tested on several benchmark problems [21]. A model based on the variant of FA to classify the data for maintaining fast learning and to avoid the exponential increase of processing units has been proposed by Nayak et al. [22].

In this paper, the considered algorithm FA is applied to the two widely used AMPs, "EDM" and "AWJM" to obtain an optimum set of the operating parameters. The FA have unique characteristics compared to the other algorithms, i.e., GA, SA, particle swarm optimization (PSO), artificial bee colony algorithm (ABC), etc. This algorithm possesses multi-modal characteristics, high convergence rate and few control parameters. It can be applied as a global problem solver to every problem domain [20]. Furthermore, on many benchmark problems this algorithm have been attempted and proved its applicability and effectiveness over other algorithms by previous researchers [20,23].

2. Firefly algorithm

Fireflies are one of the wonderful god creations whose life style of living is quite different from other creature and based on their behavior, Yang and Xingshi developed an algorithm in 2008 named as the Firefly Algorithm (FA) [23]. Fireflies are portrayed by their flashing lights and this light has two purposes, one is to fascinate breeding partners and subsequent is to deter potential beast of prey [20,23]. This flashing light obeys physics rule that intensity (I) of light decreases with the increase of distance (r), as per the equation $I = 1/r^2$. They act as an LC-oscillator that charges and discharges the light at regular time interval, $\theta = 2\pi$ [20]. In most instances, the first signallers are flying males, who attempt to fascinate female fireflies on the soil or nearby them. The responses to these signals are given by the females in terms of emitting constant or blinking lights [20,23]. Females fireflies concern with respect to behavioral modifications in the signal given by the male fireflies and they will attract toward that male firefly which is flashing optimistic light. The distance between fireflies affects the attraction between the breeding partners as the light intensity will decrease with respect to distance. Both breeding partners produce discrete signal patterns to encrypt information such as species identity and sex [20].

The approach of FA is based on a physics rule, i.e., the light intensity (I) of the firefly decreases with the increase in the square of the distance (r^2) between two firefly. The variation of intensity and attractiveness within the firefly plays substantial role in the enactment of the considered optimization technique. As the distance of the female fireflies increases from the light source, i.e., male firefly increases, the absorption of light becomes weaker and weaker. These phenomena of light intensity with respect to distance is associated with the objective function to be optimized in the algorithm. The relation is developed for the various control factors of the algorithm which affects the performance of FA. The main controlling factor is an absorption factor (γ), randomness factor (α), and randomness reduction similar to the simulated annealing process.

Metaheuristic algorithms are easy to implement and simple in terms of complexity. FA have little complexity is associated while determining the distance of the fireflies from best firefly as it's going through the two loops, one for a population of fireflies (n_f) and one outer loop for iteration (t). Furthermore, the complexity associated also increases, as the number of variables and constraint in the given problem increases. But this complexity is with all the metaheuristics algorithm. FA is a swarm-intelligence-based algorithm so it has quite similar advantages to that other swarm-intelligence-based algorithms such as genetic algorithm (GA), artificial bee colony algorithm (ABC), particle swarm optimization (PSO), etc [23]. However, FA has two major advantages compared to other swarm based algorithms: first it's automatically subdivision capability and second it's ability of dealing with multimodality. This automatic subdivision capability makes it suitable for highly nonlinear, multimodal optimization problems [23].

In recent years, FA have attracted much attention to many researchers and found different applications. The application domain of this algorithm is found in various fields of engineering such as industrial optimization, image processing, antenna design, civil engineering, robotics, semantic web, meteorology and wireless sensor network. The capability of the algorithm is not limited to these domains it has the capability to solve the optimization problem application such as continuous, combinatorial, constrained, multi-objective, highly non-linear, multimodal design problems, etc. [20]. The motivation behind this study is due to the wide applications of FA. In this paper, the authors have used the FA optimization algorithm based on its applications and suitability to handle the considered problem. In this paper, it is attempted for the parameter optimization of the machining processes, i.e., EDM and AWJM.

In FA, the population of fireflies is initialized randomly within the bounds of the process parameters. After the initialization at each iteration, parameters are updated by randomness factor (α), absorption coefficient (β), and distance between fireflies (r). In this way, these process parameters are changed and evaluated through objective function. The target function value is correlated with the previous iteration obtained value and all the iterations are carried out for finding the optimal result of the performance parameter. The maximum number of iterations (t_{max}) controls the search process.

2.1. Firefly algorithm steps

1. Initialize the random firefly positions within the limits of given problem variables and define control parameters of the FA algorithm.

Please cite this article in press as: R. Shukla, D. Singh, Selection of parameters for advanced machining processes using firefly algorithm, Eng. Sci. Tech., Int. J. (2016), http://dx.doi.org/10.1016/j.jestch.2016.06.001