# Socio-Inspired Optimization of Cutting Force in Micro Drilling of CFRP Composites for Aerospace Applications

**Aniket Nargundkar, Apoorva Shastri**

***Abstract**: The aim of this paper is to apply socio-inspired Cohort Intelligence algorithm for the minimization of cutting force for micro drilling of CFRP composites for aerospace applications. Three objective functions developed by Ravi Shankar Anand and Karali Patra are being used. These objective functions are radial force (Fx and Fy), thrust force (Fz). Four variations of CI namely Roulette Wheel Selection, Follow Best, Follow Better, and Alienation Selection have been applied. The variations of CI was coded in MATLAB (R2016a). The results are compared with experimental work. The results obtained are much better than already available results giving significant reduction in cutting forces and thereby cutting power and improvement in hole quality. As a future direction, other metaheuristics, socio based algorithms can be applied for solving the problem. Also, variations of Cohort Intelligence can be applied for constrained problems.*

***Keywords** : Micro Drilling, Cutting Forces, Variations of Cohort Intelligence, Optimization*

## I. INTRODUCTION

The turning, milling and drilling processes are the fundamental subtractive machining processes. Micro-machining is the buzz word now a days as the whole world is moving towards the miniaturization. Micro machining finds the application in various domains. Micro drilling is widely applied process for manufacturing micro holes. Micro drilling has a variety of applications for example in electronics industry, in automotive industry, in making fasteners such as micro jacks and micro pins etc. Various factors such as tool diameter, spindle speed, tool helix angle, twist angle, feed rate and material controls the hole quality thus they have to be chosen very carefully. When we shift from macro to micro, size effect comes into the consideration and hence it becomes critical to achieve good process responses in micro machining processes. For micro drilling, achieving good surface and good hole quality for assembly purposes is tough.

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There are many process parameters along with size effect of tool such as speed, tool geometry, feed and machining conditions which governs the quality of hole and thus the selection and optimum combination of such parameters becomes critical. When we shift from macro to micro, burr formation phenomenon changes drastically as the internal surface is greatly affected by such burrs which might effect on product functionality and reliability. In macro-level, removing such burrs is relatively easy task as we can control the macro size.

However, in case of micro holes, it is very difficult because of the poor accessibility of burr area along with stringent tolerances applied. Hence, in the past various scientists have tried to study this process with experimental set up and theoretical studies [1-4]. Carbon fiber reinforced plastic (CFRP) composite material is an advanced composite which finds its practical application in various industry sectors such as aviation and automobile. Now a days steels and aluminium are getting replaced with this CFRP. It has properties such as high stiffness, high strength to weight ratio and good damping properties [5] Automobile and aviation components are nowadays fabricated with CFRP. The components have typical micro hole features. The cutting mechanism in micro drilling is analyzed by studying traditional mechanical drilling with size effect. It is the downscaling of traditional mechanical drilling[6]. During micro drilling process, the undeformed chip thickness reduces gradually, thus non linearly increasing the forces in radial direction [7]. The add on effect of increased ploughing takes place at lower feed rates and thus tool wear increases or sudden tool breakage could take place [8]. The process parameters such as feed, speed, ultrasonic vibrations produced in drills, and the workpiece fixturing were investigated for the delamination in CFRP drilling, with the special focus on the internal delamination damages. Based on both the experimental and theoretical analysis, the fixturing effectiveness and the feed was investigated as well[9]. The modeling of tool wear on force through experiments and theory analysis was provided. A Finite Element Method has been used to develop the model of force. This is based on the mathematical idea of flank wear size and morphology. Finally the theoretical model is verified by the multivariate experiments, and the results show that proposed model can work well[10]. acoustic emission (AE) signals are used to monitor AWJ machining of stacked titanium-CFRP.

Owing to the non-stationary nature of the AE signals, this work is focused on the precision-driven predictive approach in simultaneous time-frequency domain[11]. Ravi Shankar Anand and Karali Patra has done experimental study to investigate feed and cutting speed effect on cutting force components and hole quality. Analysis of variance based regression equation is used to predict cutting forces and hole quality and their trend are described by response surface methodology[12].

Various nature inspired optimization algorithms are proposed and applied to optimize the process parameters of machining of CFRP composites. As discussed above, optimizing the process of CFRP micro hole machining is critical because of the size effect involved in micro machining. Kulkarni et. Al developed a socio based optimization approach referred to as Cohort intelligence (CI) in which group of people interact with one another to obtain the solution which is globally acceptable. Here, roulette wheel approach is used by the people referred as candidates in the algorithm to decide whom to follow in order to achieve best solution. In this way, supervised lerning is achieved by the candidates and using reduction factor to shrink the sampling space, candidates are moving towards global solution and not getting trapped into local minima. Algorithm was validated by solving several benchmark problems and have been applied for various engineering applications. The best possible value of goal is said to be attained if objective function converges to optimal value for substantial number of iterations or the performance of few candidates fail to improve significantly [13]. In addition to this, other than roulette wheel approach, seven different variations for follow mechanism for candidates have been proposed by Patankar and Kulkarni in 2018[14]. The so far applications of CI algorithm include truss design problem by Kale and Kulkarni in 2018 [15], 0-1 Knapsack problem by Kulkarni and Shabir in 2016[16] and constrained mechanical engineering problems (Shastri et al. 2019)[17]. The variations of CI were applied on AWJM process parameter optimization by Gulia and Nargundkar [19]. Modified version of CI known as Multi-CI with intra and inter group learning mechanism is proposed by Shastri and Kulkarni in 2018[18].In this paper four variations of CI : Alienation, follow best, follow better and roulette wheel are applied to optimize cutting forces in x, y and z direction for micro drilling of CFRP composites. Results obtained using socio inspired algorithm are comparable to experimental results.

This paper is arranged as follows: Section II describes the framework of Variations of CI along with flowchart. Section III describes the problem formulation for cutting forces in x, y and z directions. Results, followed by the comparison with experimental work are provided in section IV. The conclusions and a comment on future direction is mentioned at the end in section V.

## II. METHODOLOGY

### Variations of CI

Out of different variations of CI proposed by Patankar and Kulkarni, four variations are applied on the micro drilling of CFRP optimization problem, which are roulette wheel selection, follow better, follow best and alienate random candidate -and- follow random from remaining.

The algorithm steps are describe below:

**Step 1:** The number of candidates and reduction factor are defined at initialization.

**Step 2:** The value of objective function is calculated and the probability of behaviour selection for every candidate c is found.

**Step 3:** Here, follow mechanism of candidates are determined based on the strategies given below.

(a) **Follow best:** The candidate having highest probability is highest, is followed in this rule.

(b) **Follow better:** Candidate c follows a candidate having probability of selection better than itself.

(c) **Roulette wheel:** Here, the roulette wheel approach is applied for following.

(d) **Alienation:** For this approach, every candidate c overlooks a candidate at the beginning and the candidate follows the random behavior excluding the isolated candidate.

**Step 4:** Sampling interval reduction factor is applied and range for each candidate is shrink. After that, steps 1 to 4 are repeated until the convergence is achieved as shown in flow chart.

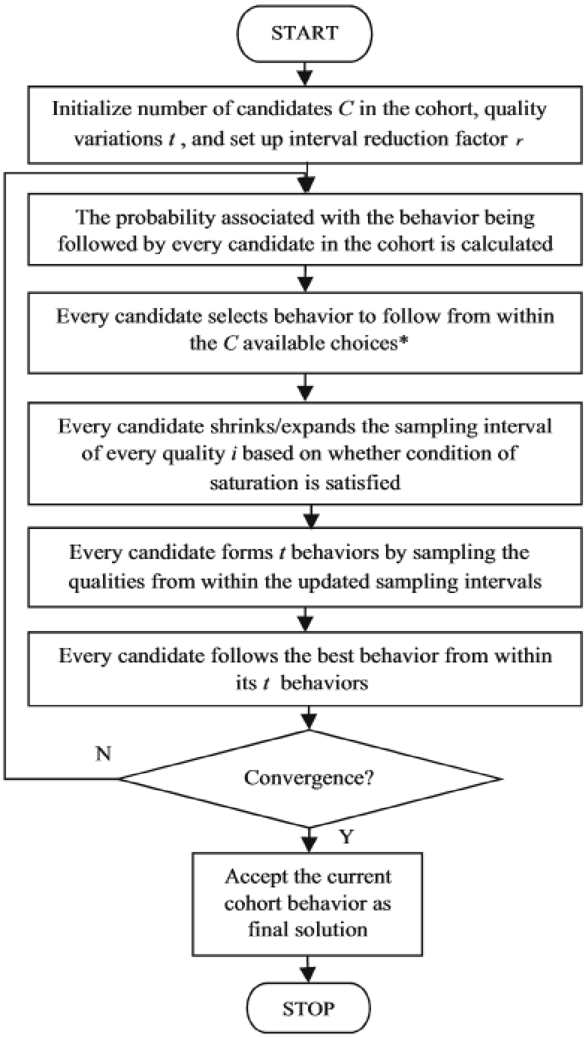


**Fig. 1. Flow Chart of CI Algorithm[13]**

## III. PROBLEM FORMULATION

Authors have selected case study based on Ravi Shankar Anand and Karali Patra [7]. In the referred paper, experiments were conducted for different set of cutting speed and feed ranging from 15.7 to 39.2 and 1 to 5 respectively. Regression equations are obtained for cutting forces in there directions as given below.

Eq.1, 2, and 3 presents the objective function of Fx, Fy, and Fy respectively. Upper and lower bounds of each of the variables viz. cutting speed $V$ and feed $f$ are also mentioned.

$$F_x = 0.38607 - 0.014983 * V - 0.13220 * f + 0.0012 * f * V + 0.0003 * V^2 + 0.019583 * f^2$$

**Eq 1**

$$F_y = 0.25371 - 0.00375 * V - 0.12116 * f + 0.00063 * f * V + 0.000093 * V^2 + 0.021 * f^2$$

**Eq 2**

$$F_z = 0.64841 + 0.078424 * V + 0.59493 * f - 0.0017 * f * V - 0.0009 * V^2 - 0.0204 * f^2$$

**Eq 3**

Where,
$15.7 \leq V \leq 39.2$
$1 \leq f \leq 5$

## IV. RESULTS AND DISCUSSION

The variations of CI algorithm coded in MATLAB R2019 on Windows Platform with an Intel Core i3 processor and 4 GB RAM. The control parameters associated with the variations of CI for solving the micro drilling of CFRP problem are reduction factor r = 0.99, and no of candidates = 5. Every problem is solved 30 times. In Table I, best and mean solutions for Fx, Fy and Fz along with associated standard deviation obtained using variations of CI are shown. The solutions obtained using variations of CI such as follow best, follow better, roulette wheel and alienation have been compared with the experimental results as shown in Table II.

**Table I: Statistical solutions to Problems using Variations of CI**

(Mean = Mean solution; Std. Dev. = Standard-deviation of mean solution; Best = Best solution; Runtime = Mean runtime in seconds)

| Machining Process | Objective Function | Optimized value | Algorithms Applied<br>Variations of CI | | | |
|---|---|---|---|---|---|---|
| | | | Roulette Wheel | Follow Best | Follow Better | Alienation |
| Micro Drilling | Fx | Mean | 0.0569 | 0.0569 | 0.0569 | 0.0569 |
| | | S.D. | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | Best | 0.0569 | 0.0569 | 0.0569 | 0.0569 |
| | | Run Time (Sec) | 0.73 | 0.94 | 0.78 | 0.79 |
| | Fy | Mean | 0.0704 | 0.0704 | 0.0704 | 0.0704 |
| | | S.D. | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | Best | 0.0704 | 0.0704 | 0.0704 | 0.0704 |
| | | Run Time (Sec) | 0.98 | 0.63 | 0.96 | 0.83 |
| | Fz | Mean | 2.2057 | 2.2057 | 2.2057 | 2.2057 |
| | | S.D. | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | Best | 2.2057 | 2.2057 | 2.2057 | 2.2057 |
| | | Run Time (Sec) | 0.81 | 0.76 | 0.64 | 0.82 |

**Table II: Comparison of Algorithms**

| Objective Function | Experimental | Roulette Wheel | Follow Best | Follow Better | Alienation |
|---|---|---|---|---|---|
| Fx | 0.095 | 0.0569 | 0.0569 | 0.0569 | 0.0569 |
| Fy | 0.108 | 0.0704 | 0.0704 | 0.0704 | 0.0704 |
| Fz | 0.108 | 2.2057 | 2.2057 | 2.2057 | 2.2057 |

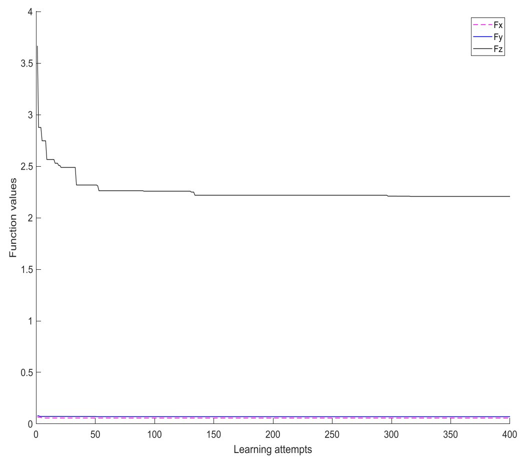


**Fig.2a. Best solution for Alienation**

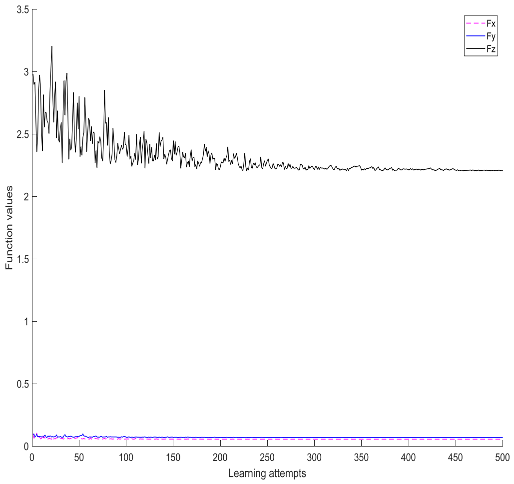


**Fig. 2b. Best solution for Follow Best**

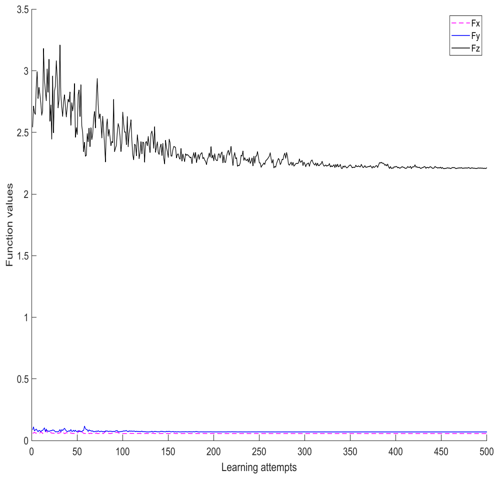


**Fig. 2c. Best solution for Follow Better**

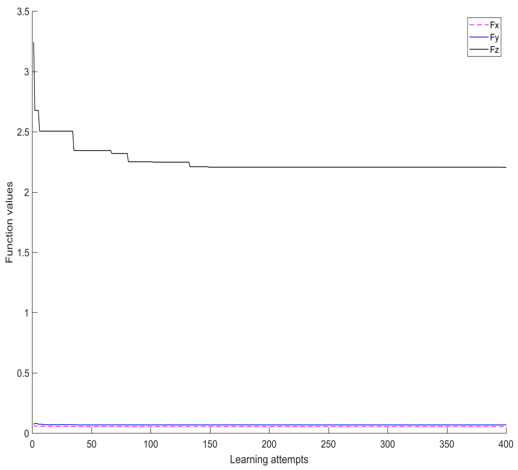


**Fig. 2d. Best solution for Roulette Wheel**

Fig. 2a to 2d shows convergence obtained by different variations of CI such as alienation, follow best, follow better and roulette wheel respectively. In follow best and follow better approaches, candidates follow one of the candidates from the cohort. Hence, solutions are getting trapped in local minima as indicated in fig. 2b and 2c, as learning proceeds, the best and better candidate, jump out of local minima and eventually for all candidates the global minimum is obtained. Unlike follow better and follow best approaches, it is evident from fig. 2a and 2d, alienation and roulette wheel approach have shown significant difference in follow mechanism and results in global solution without trapping into local minima. It is evident from table II that results obtained using variations of CI are much better and robust as compared with experimental work.

## V. CONCLUSION AND FUTURE DIRECTION

In this paper, four variations of socio inspired optimization algorithm CI have been successfully applied on cutting force reduction of micro drilling of CFRP composites for aerospace applications. Results are compared with the experimental work and has shown significant reduction in cutting forces in three directions. Due to reduction in cutting forces, tool life is improved, tooling cost is minimized and high machining efficiency could be obtained. In near future, authors intend to apply contemporary algorithms for the same problem and validate the results using confirmation experiments.

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