Genetic Algorithm for Multiobjective Optimization: Applied in High Speed Machining

Milling Operation

Hicham Mokhtari[1], Mohamed Arezki Mellal[1], Idir Belaidi[2], Said Alem[1], Sofiane Berrazouane[2], Mahdi Ouziala[3]

[1]Solid Mechanics and Systems Laboratory-FSI-M'Hamed Bougara University, Boumerdès, Algeria, [2]LEMI Laboratory-FSI-M'Hamed Bougara University, Boumerdès, Béjaia, Algeria, [3]University of Béjaia, Algeria

mellal.mohamed@gmail.com

***Abstract*-Genetic Algorithms (GAs) are general-purpose heuristic search algorithms that mimic the evolutionary process in order to find the fittest solutions. The algorithms were introduced by Holland in 1975. Since then, they have received growing interest due to their ability to discover good solutions quickly for complex searching and optimization problems. Simple genetic algorithms have been developed to solve the problems of multi objective optimization, such as NSGA II. The objective of this research is to apply the elitist non-dominated sorting GA (NSGA-II) for multi-objective optimization problems in case of high speed machining for the milling operation. The implemented model under Matlab, allows, from a considered space research. We have optimized the values of V_c and f, for an imposed Depth, while the production cost and time are minimized, under technical constrains of the production system.**

Keywords-Multi-objective Optimization; Genetic Algorithm NSGA-II; Pareto Front; Milling Operation

I. INTRODUCTION

The search for best performance, best quality at the lowest cost, is a major issue in the industrial field. The optimization of cutting conditions in serial manufacturing of industrial products by material removal is an essential step in the mechanical production. In this case, we have many methods and mathematical tools for multi-objective optimization, namely non-deterministic or stochastic methods such as simulated annealing, ant colony, tabo search, genetic algorithms, etc.

However, many works have been realized such as K. Deb et al [1] and C. M. Fonseca [2] for mathematical studies about non-dominated sorting genetic algorithm (NSGA II). G.P. Rangaiah [3] has presented a stat of art for multi objectives optimisation methods. Then, R. T. Marler [4] has realized large studies about the multi-objective optimization methods for engineering.

In this paper, we propose to use the algorithm genetic NSGA-II that is based on multi objectives optimization for milling operation in high speed machining. The dependability and the precision instrument of this type of machine were studied in [5], [6]. The purpose of this approach is to find the optimal a set of optimal values for V_c and f, for an imposed depth, while the production cost and time are minimized, under technical constrains of the production system.

II. MULTI-OBJECTIVE OPTIMIZATION PROBLEM

Mathematically, we can write multi-objective optimization problems as follows, Dias [7]:

$$\text{Minimizing } y = f(x) = \{f_1(x), f_2(x), \ldots\ldots, f_M(x)\} \quad (1)$$

$$\text{Subject to: } g(x) = \{g_1(x), g_2(x), \ldots., g_j(x)\} \le 0$$

$$h(x) = \{h_1(x), h_2(x), \ldots., h_k(x)\} = 0$$

$$\text{where } x = \{x_1, x_2, \ldots., x_N\} \in X$$

$$y = \{y_1, y_2, \ldots., y_N\} \in Y$$

x is the vector of decision variables, y is the objective vector; X is the decision space and Y is the objective space. The solution of equation (1) is usually not unique, but a set of non-dominated solutions is called Pareto-Optimal set [2].

III. OBJECTIVES FUNCTIONS

The economic aspect is the ultimate goal for each industry, in Fact, time and cost factors of production are indispensable to increase the profit of the company, so we always try to have a final product with a lower cost in minimum time.

A. Formulation of the Time Production

The general expression for the time of production is given by J.S. Agapiou [8]:

$$T_u = t_c + t_a + t_{c_0} \cdot \left(\frac{t_c}{T}\right) \quad (2)$$

Then, according to generalized law of Taylor, we can write:

$$V_c = T^n . k . f^p . a^q \quad (3)$$

Also, the formulation of technological time is given by [7] as follows:

$$t_c = \frac{L_{tool}}{V_f} \quad (4)$$

After that, we can calculate V_f and N by the following formulations:

$$V_f = f . z_n . n \ , \quad N = \frac{1000 V_c}{\pi . D} \quad (5)$$

We replace the equations (3, 4, and 5) in equation (2), we obtain the general formulation of time production:

$$T_u = \left(\frac{PDL_{tool}}{1000.z}\right) f^{-1} V_c^{-1} + t_a + t_{co} \cdot \left(\frac{PDL_{tool}}{1000.z}\right) . k^{\frac{1}{n}} V_c^{-\left(\frac{n+1}{n}\right)} . f^{\left(\frac{p-n}{n}\right)} . a_p^{\frac{q}{n}} \quad (6)$$

B. *Formulation of Cost of Production*

The general expression for the time of production is given by [10], as follow:

$$P_u = P_0 t_a + P_0 t_c + P_a + P_l \cdot \left(\frac{t_c}{T}\right) \tag{7}$$

We replace the equations (3, 4, and 5) in equation (7), we obtain the general formulation of cost of production:

$$P_u = P_0 \cdot t_u + P_0\left(\frac{L_{tool}}{f \cdot z \cdot n}\right) + P_a + P_l\left(\frac{\left(\frac{L_{tool}}{f \cdot z \cdot n}\right)}{T}\right) \tag{8}$$

IV. EXPRESSION OF MACHINING CONSTRAINTS

Machining constraints are presented in the following manner:

A. *Constraints Related to the Power of Machine*

The formulation is given by Agapiou [8]:

$$P_c = \frac{\pi}{60} \cdot D \cdot e_m \cdot a_r \cdot z_e \cdot F_{cs} \cdot N \le P_{useful} \tag{9}$$

Then:

$$e_m = \left(\frac{f\left[1+\sqrt{1-\frac{a_r^2}{D^2}}\right]}{z}\right)\sin\varphi \tag{10}$$

Add:

$$F_{CS} = F_{cs_0} \cdot \left[1-0.02\left(\gamma-\gamma_0\right)\right] \cdot \left(\frac{e_m}{e_0}\right)^{-0.3} \tag{11}$$

We replace the equations (10, 11) in equation (9), and obtain the general formulation of the power machine:

$$P_c = \frac{100.a_r.F_{cs0}\cdot\left[1+\sqrt{1-\frac{a_r^2}{D^2}}\right]\cdot\left[\left[1-0.02\left(\gamma-\gamma_0\right)\right]\right]\cdot\left(\frac{2.\left[1+\sqrt{1-\frac{a_r^2}{D^2}}\right]}{e_0.z.D}\right)^{-0.3}.\arcsin\frac{a_r}{D}}{3.D.\pi} . f^{0.7} V_c . a_p^{0.7} \le P_{utile} \tag{12}$$

B. *Constraints Related to the Cutting Force*

The formulation is given by [9]:

$$C_p = F_c \frac{D}{2} z_e \le C_{P_{Max}} \tag{13}$$

Then:

$$F_c = e_m \cdot a_r \cdot F_{cs} \tag{14}$$

We replace the equations (10, 11) in equation (13), we obtain:

$$C_p = \frac{100.a_r.F_{cs0}\cdot\left[1+\sqrt{1-\frac{a_r^2}{D^2}}\right]\cdot\left[1-0.02(\gamma-\gamma_0)\right]\cdot\left(\frac{2.\left[1+\sqrt{1-\frac{a_r^2}{D^2}}\right]}{e_0.z.D}\right)^{-0.3}.\arcsin\frac{a_r}{D}}{\pi} . f^{0.7} . V_c . a_p^{0.7} \le C_{P_{Max}} \tag{15}$$

C. *Constraints Related to the Maximum Deflection of the Tool*

The formulation is given in [10]:

$$f_L = \frac{K_F a_p f^{0.7} L_{tool}^3}{2.4ED^4} \le F_{L_{Max}} \tag{16}$$

Then

$$K_F = F_{cs_0} \cdot \left[1-0.02\left(\gamma-\gamma_0\right)\right] \cdot \left(\frac{\sin k_r}{e_0}\right)^{-0.3} \tag{17}$$

We replace the equation (17) in (16), we obtain:

$$f_L = \frac{F_{cs0} \cdot \left[1-0,02.\left(\gamma-\gamma_0\right)\right] \cdot \left(\frac{\sin K_r}{e_0}\right)^{-0,3} . L_{outil}^3}{2,4.E.D^4} . f^{0,7} . a_p \le f_{L\max} \tag{18}$$

D. *Constraints Related to the Surface State*

$$R_t = \frac{f^2}{8z.\left(D \mp \frac{z}{\pi}\right)} \le R_{t_{Max}} \tag{19}$$

E. *Constraints Related to the Temperature of Cutting*

The formulation is given in [11], as follows:

$$74.96 \cdot V_c \cdot 0.4 \cdot f^{0.2} \cdot a_p^{0.105} - 17.8 \le T_{P_{Max}} \tag{20}$$

V. SEARCH SPACE ABOUT V_c AND f

$$V_{c_{min}} \le V_c \le V_{c_{max}}$$

$$f_{\min} \le f \le f_{\max}$$

VI. MAIN LOOP OF GENETIC ALGORITHM NSGA II

The main loop of genetic algorithm NSGA II is proposed by Deb et al. [1]:

- Initially, a random parent population P_0 is created.
- Tournament selection, recombination and mutate operators are used to create a child population Q_0 of size N.
- $R_t = P_t \cup Q_t$ combine parent and children population.
- Calculate the crowding distance in F_i of R_t add P_{t+1} until the size of P_{t+1} is equal to N.

VII. EXPERIMENTAL RESULTS

A. *Parameters of the Cutting*

TABLE I CUTTING PARAMETERS

f_{min}	f_{max}	$V_{c\ min}$	$V_{c\ max}$	$P_{c\ max}$	C_{max}
0.15	0.55	10000	30000	10	20000
L_{tool}	D_{tool}	P_l	P_a	z	a_r
160	6	14.17	0.8	8	100
$f_{L\ max}$	T_{ref}	P_0	t_a	T_{max}	t_{c_0}
2	45	0.26	0.05	700	0.20

B. *Parameters of the NSGA-II*

Initial population: Pop = 100 individuals; Sub-Pop: 5; Selection: by tournament; crossover rate: 0.8, Mutation rate: 0.01; Generation number: 200; Number of objective functions: 2 fitnesses. Number of constraints: 5.

C. *Discussion*

After several iterations implemented in MATLAB using a computer Intel Core 2 Duo, CPU=2.93 GHz, RAM= 2 Go. We visualize the results presented in Fig.1 as the sets of solution of non-dominated individuals and dominated individuals in Pareto front.

Then, we show the solution space for non-dominated and dominated individuals regrouped at $f = 0.55 mm/tr$ in Fig. 2, Fig. 3, and Fig. 4 show the variation of objectives in sub-population during 200 generation and individuals values during 200 generations respectively.

We obtained the optimal values for V_c and f, then the minimum values of production time T_u and cost of production P_u are presented in Table II.

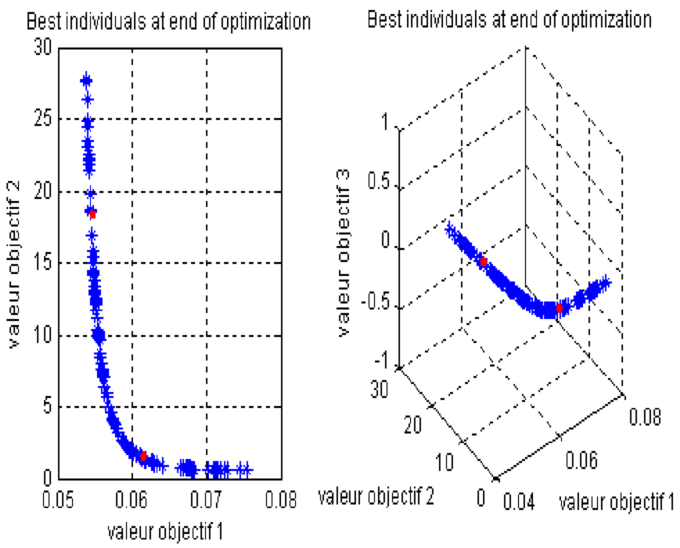

Fig. 1 Space Pareto front (All non dominated individuals in blue and dominated individuals in red color)

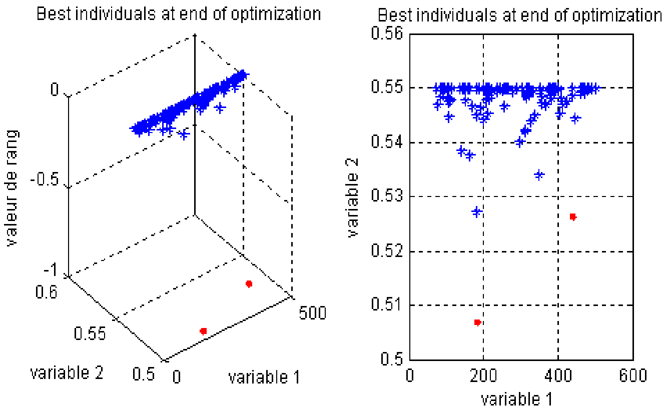

Fig. 2 Solution space for all non dominated individuals with blue and dominated individuals with red regrouped at $f = 0.55 mm/tr$

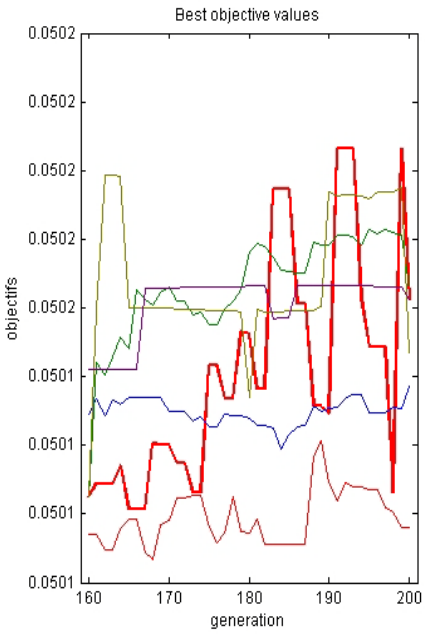

Fig. 3 Variation of the objective functions in sub-population during 200 generations

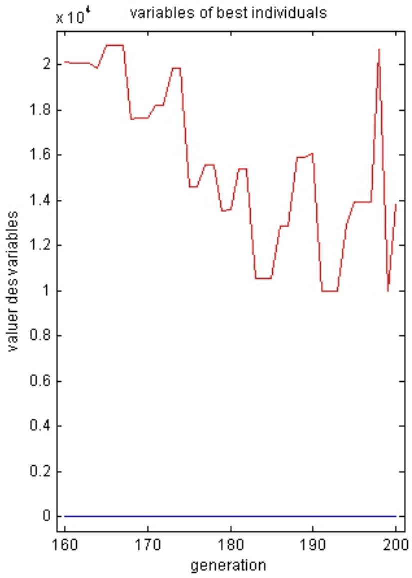

Fig. 4 Individuals values during 200 generations

TABLE II EXPRIMENTAL RESULTS

a_p (mm)	T_u (min)	P_u (€)	V_c (mm/s)	f (mm/turn)	CPU
0.9	0.0501	6.8819	20885	0.54908	0.30
1.3	0.0501	3.9336	14462	0.5475	0.30
1.5	0.0500	30.26	27216	0.5499	0.30
1.9	0.0501	6.4725	14425	0.55	0.31
2.5	0.0500	33.054	22102	0..5441	0.30
3	0.0501	32.97	20270	0.5498	0.30
4	0.0501	34.831	18054	0.5496	0.30

VIII. CONCLUSIONS

In this paper, we presented a multi-objective optimization solution for high speed machining applied to the milling operation using the non-dominated sorting genetic algorithm NSGA II. The results obtained prove the efficiency and accuracy of the genetic algorithm NSGA II for our process.

The major problem in the application of genetic algorithms is the number of generation, which is based on the results obtained by the algorithm, i.e. there is not a rule to determine the number of generation. In future, we generalize this approach to other machining processes.

REFERENCES

[1] K. Deb, S. Agrawal, A. Pratap and T. Meyarivan, "*A fast elitist non dominated sorting genetic algorithm for multi-objective optimization: NSGA-II,"* In M. S. et al. (Ed.), Parallel Problem Solving from Nature – PPSN VI, Berlin, Germany: pp. 849–858.Springer-Verlag, 2000.

[2] C. M. Fonseca and P. J. Fleming, "Genetic algorithm for multiobjectives optimization: formulation, discussion and generalization," in *Proc. Fifth Internationa Conference on Genetic Algorithms*, San Mateo, pp. 416-423., 1993.

[3] G. P. Rangaiah, "multi-objective optimization - techniques and applications in chemical engineering," World Scientific Publishing Co. Pte. Ltd. Edition; Har / Cdr, Chap 1, 2008.

[4] R. T. Marler and J.S. Arora, "Survey of multi-objective optimization methods for engineering," *Structure Multidisciplinary Optimtimization Journal*, vol. 26, pp 369–395, 2004.

[5] M. A. Mellal, S. Adjerid and D. Benazzouz, "Modeling and simulation of mechatronic system to integrated design of supervision: using a bond graph approach," *Applied Mechanics and Materials*, vol. 86, pp. 467–470, 2011.

[6] M. A. Mellal, S. Adjerid and D. Benazzouz, "Modeling and simulation of mechatronic system to integrated design of supervision: using a bond graph approach," in *Proc. ALC'11*, Seoul, South Korea, 2011.

[7] A. H. F. Dias and J.A. de Vasconcelos, "Multiobjective genetic algorithm applied to solve optimization problems," *IEEE Transactions on Magnetics*, vol. 38, no. 2, pp 1133–1136, 2002.

[8] J. S. Agapiou "The Optimization of Machining Operations Based on a combined Criterion: Part 1: The Use of Combined Objectives in Single-pass Operation," *Journal of Engineering for Industry*, vol. 114, pp 500–507, 1992.

[9] H. Mokhtari, "Contribution à l'elaboration d'une base de données COM en UGV, basée sur l'optimisation multiobjectif par l'algorithme genetiue NSGA II," M.s. Thesis, University of M'Hamed Bougara, Boumerdes, Algeria, 2009. (in french).

[10] I. Belaidi, "un modèle base sur l'algorithme NSGA-II pour l'optimisation des paramètres de tournage," 10ème c Colloque de l'Innovation AIR-PRIMECA, La plagne, France, 2007. (in french).

[11] H. Mokhtari, I. Belaidi and S. Berrazouane, "optimisation multi-objectif par l'algorithme genetique NSGA II des parametres de coupe en fraisage en bout conventionnel et UGV," in *Proc. of the CMSM'2011: 4th International Congress : Design and Modeling of Mechanical Systems*, Sousse, Tunisia, 2011.

Mokhtari Hicham received his B.S. degree in 2007 from the Faculty of Engineer Sciences, University of M'Hamed Bougara, Boumerdes, Algeria, and his M.S degree in mechatronics in 2009 from the same university. Since 2010, he is a PhD candidate in the Laboratory of Solid Mechanics and Systems at the same university. He also works as a contract teacher and he participated in national and international conferences.

Mellal Mohamed Arezki is a PhD candidate in mechatronics at the Solid Mechanics and Systems Laboratory, FSI, M'Hamed Bougara University, Algeria. He participated in several national and international conferences: Korea, China, Poland, Tunisia and he is an author of papers in journals. His research interests: dependability, study of complex systems, bond graph modeling, genetic algorithms and ant colony optimization. He also works as a contract teacher.

Belaidi Idir is a lecturer at the Laboratory of Energetics - Mechanics and Engineering, M'Hamed Bougara University, Algeria. His research interests: Mechanical engineering**.**

Alem Said is a PhD candidate in mechatronics at the Solid Mechanics and Systems Laboratory, FSI, M'Hamed Bougara University, Algeria. His research interests: bond graph and di-graph modeling, dependability, sensor placement optimization and automation control. He also works as a contract teacher.

Berrazouane Sofiane is a PhD candidate in mechatronics at the Laboratory of Energetics - Mechanics and Engineering, FSI, M'Hamed Bougara University, Algeria. His research interests: renewable energy, fuzzy logic, particle swarm optimization. He also works as a contract teacher.

Ouziala Mahdi is a PhD candidate at Béjaia University, Algeria. His research interests: fuzzy clustering, fuzzy logic, and automation control.