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Machining Parameter Optimization for Cylindrical Part in CNC Turning Centre Using Mathematical Model and Genetic Algorithm Approach

Abhishek Agrawal[1], Dr. R.S. Rajput[2], Dr. Nitin Shrivastava[3]
PhD Scholar[1], Professor & Director[2], Assistant Professor[3]
Department of Mechanical Engineering, University Institute of Technology, Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal-462036(Madhya Pradesh), INDIA

***Abstract*: This paper presents machining parameters (turning process) optimization based on the use of artificial intelligence. To obtain greater efficiency and productivity of the machine tool, optimal cutting parameters have to be obtained. In order to find optimal cutting parameters, the genetic algorithm (GA) has been used as an optimal solution finder. Optimization has to yield minimum machining time and minimum production cost, while considering technological and material constraints.**
***Keywords*— Multi-objective optimization, machining parameters, Genetic Algorithm, CNC turning center.**

I. INTRODUCTION

Today machining process planning has to yield such results that are to give maximum productivity and to ensure economy of manufacturing. Today the market has an ever changing demand for new products, which require shorter development cycle. An important part of the product development cycle is manufacturing process planning. Shorter process planning time can lead to the use of machining parameters that are not optimal and this can lead to the greater cost of production. A human process planner selects proper machining parameters by using not only his own experience and knowledge but also from handbooks of technological requirements, machine tool, cutting tool and selected part material. This manual selection can be slow and does not have to give optimal results.

To overcome that problem, machining process planning has gone automated, by the use of Computer-Aided Process Planning (CAPP) system. In addition to operation sequence and machining parameters, the CAPP system should also be able to automatically choose machine and cutting tool while taking in consideration part material. In this paper, the focus is given to cutting parameters optimization. Cutting parameters, such as cutting depth, number of passes, feed rate and machining speed have influence on overall success of machining operation 1,2 . In order to conduct optimization, a mathematical model has to be defined. It is not always easy to define a model that can be expressed by pure analytical functions. Besides, cutting parameters optimization presents a multi-objective optimization problem, so the classical mathematical methods such as linear programming would not work with such input data. There is also a problem of finding local optimum.

In order to overcome these problems, this paper shows the use of Genetic Algorithm (GA) in machining process optimization. GA is a part of the evolutionary algorithms that copy intelligence of nature in order to find global extremities on the given function problem.

These algorithms are based on stochastic operations. In nature, only an entity that is able to adapt to its surrounding is going to survive and transfer its qualities to next generation 3,4 . Depending on measuring the quality of entity, the proposed result is kept or deleted. New combined results are then transferred to the next generation that should now consist of better results, closer to a global optimum. Whole process is terminated when stopping criteria are met and a global optimum is found. GA ensures that the calculated result is global or close to the global optimum.

The given example is based on optimizing cutting parameters in turning process, which is one of the two processes that are the most common operations performed on the modern CNC machines. In the first case the goal function (Figure 1.) was minimum production time and in the second case the minimal power consumption 5,6,7 . The first case is applicable when we have requirements for the production of smaller product series, which have to be manufactured in short time. The second case could be used when we want to define ma-chining process which is to meet the cutting power limitations of our manufacturing equipment.

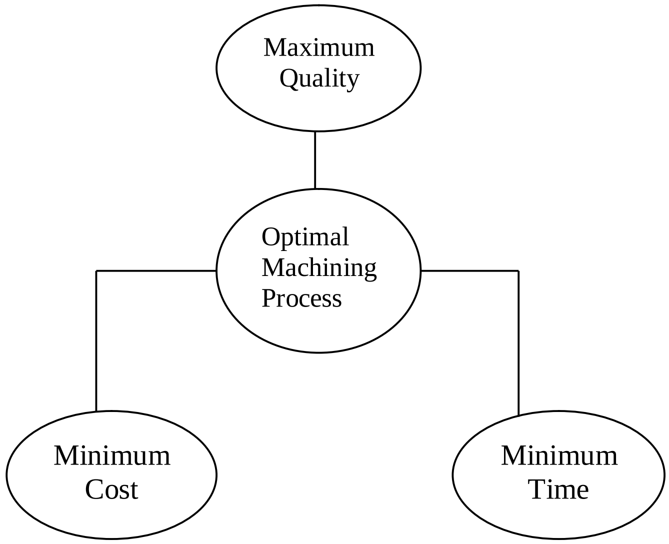

Fig.1 Possible Optimization Goals

II. MODEL DESIGN

In this paper a procedure for optimization of turning process parameters on CNC turning center has been applied. Optimization has been carried out by defining goal functions - minimum production time. The mathematical model that describes machining operation has been defined as a combination of those functions whose variables are necessary for cutting parameters. The mathematical model consists of three separated models:

1) *Tool Life model*,

$$T^m = \frac{c_{v1}}{v_c a_p^{x_{v1}} \left(\frac{HB}{200}\right)^{n_t}} k_1 k_2 k_3 k_4 k_5 k_6 k_7 k_8 k_9$$

where: v_c – cutting speed, a_p – cutting depth, f – feed, x_{v1}, y_{v1} – coefficient defined by material, HB – hardness of material, n_t – exponent of influence of the hardness of material, m – exponent of relative tool life, C_{v1} – techno-logical proportional coefficient, k_1 k_2 k_3 k_4 k_5 k_6 k_7 k_8 k_9 – influential technological coefficients (experimentally obtained), correction coefficient

2) *Cutting force model*,

$$F_z = C_{pz} a_p^{x_{pz}} f^{y_{pz}} HB^{n_{pz}} k_m k_\chi k_r k_\gamma k_h \cdot 9{,}81$$

where: C_{pZ} – technological proportional coefficient, a_p – cutting depth, f – feed, x_{v1}, y_{v1} – coefficient defined by type of turning operation, HB – hardness of material, n_{pZ} – exponent of influence of the hardness of material, k_m k_x k_r k_y k_h – influential technological coefficients (experimentally obtained), correction coefficient

3) Cutting power model

$$P = \frac{F_z c_c}{60 \cdot 1000}$$

where: F_z – main cutting force, v_c – cutting speed

Tool life model has been integrated in goal function, while cutting force and power model represented constrain functions, as shown in Figure 2.

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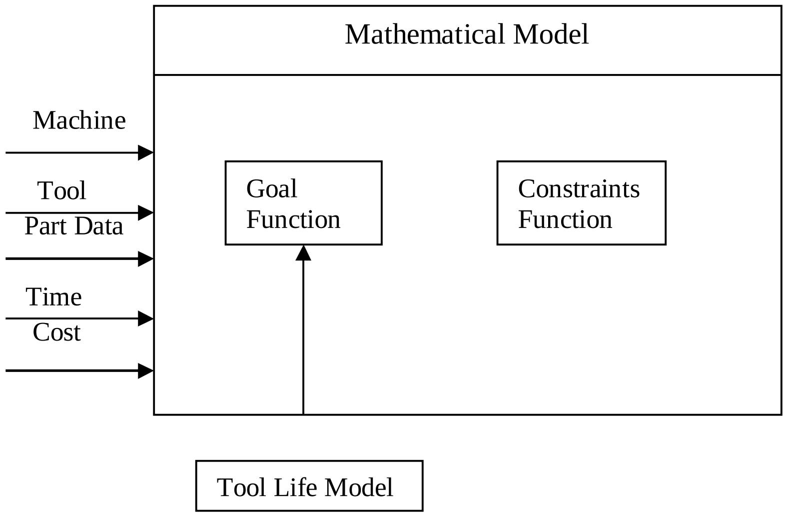

Figure 2. Optimization model

Model input data is the machine and tool data information of part material and shape, as well as time and cost limit of manufacturing. Input data has been prepared on the basis of the technical data sheets of the machine manufacturer and chosen tool. Parameters referring to the type of the part material have been gathered as influence coefficients from analytical experiment data. The experiment has been performed on the CNC lathe, and a steel bar has been machined with of SANDVIK T-MAX P CNMM-190616 tool. The lathe has 30kw spindle power, maximal cutting forces F_{zmax} of 6300N and F_{xmax} of 5000N. The workpiece characteristics are as follows: diameter 80mm; workpiece length 200mm, material is low alloy steel with HB = 180. Model output is presented with cutting parameters which satisfy constrain functions at the end of optimization process and give optimal value of goal function, which is a global minimum.

The mathematical model has been programmed in MATHLAB ™. As basis for GA we used MATLAB's GA toolbox ™. For GA, standard settings have been taken. For each depth of cutting optimization process, the optimal cutting parameters have been given. GA converges until the stopping criteria are met. In order to obtain optimal cutting parameters, a number of passes have been decided. In this case binary linear programming optimization (LP) method has been the best choice 9,10 . The whole optimization process can be represented by the block diagram, Figure 3.

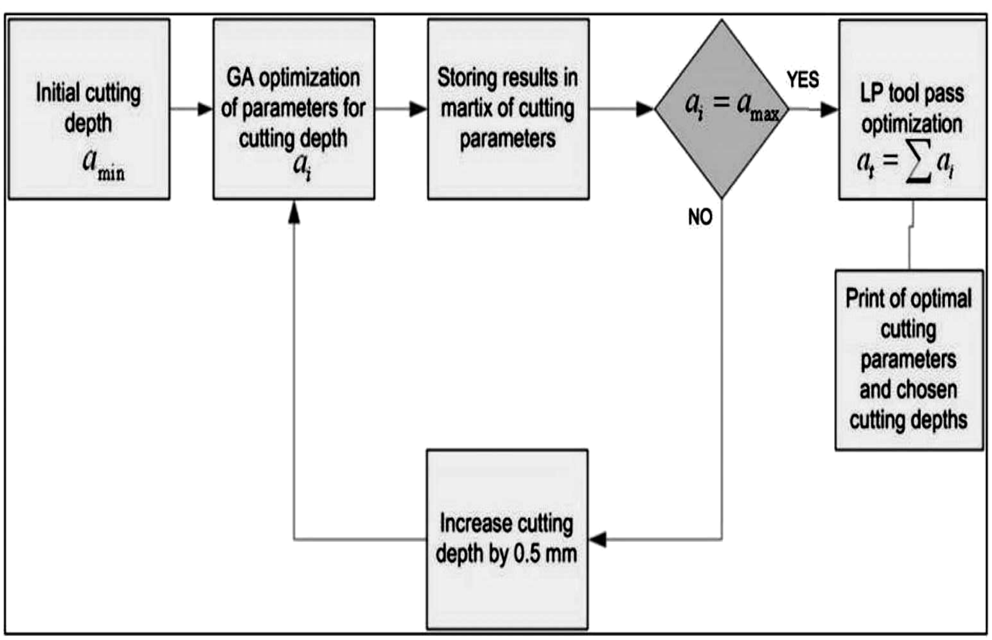

Figure 3. Block Diagram of Optimization Process.

III. EXPERIMENTAL RESULTS

The optimization procedure is applied on the turning centers. The success of optimization depends on defining the goal function - minimum production time (4).

$$t_1 = t_g + t_a + t_p$$

where: t_g – main machining time, t_a – tool change time, t_p – time during which the tool do not cut

$$t_g = \frac{L_t}{nf}$$

where: n – main spindle frequency, L_t – total length of tool path

A GA has been selected in search for the optimal solution. In the proposed GA, the advantage of multi-dimensional search scheme of GA has been used in finding a candidate for replenishment. The basic GA setup properties are the following: population size (20 individuals); coding (performed with real numbers); stochastic uniform selection has been applied (SUS); number of elite children (2); genetic operators: those individuals that survive the selection step, undergo alteration by two genetic operators -the crossover and mutation; the uniform crossover was selected; probability for crossover (0.8); mutation rate (0.1); termination conditions (two rules are used to stop this GA, the first one is a fixed number of generations (100 generations), and the second one stops the evolutionary process if the best-on-hand solution has shown no improvement in the last 50 generations. The LP has been used to give number of tool passes that meet the requirement of total roughing depth and minimum cutting time. The method outputs the binary matrix from which the row of optimization results of matrix has been selected, satisfying cutting parameters goal function.

A. Minimization of Production Time

Using previously defined methodology, both optimization of the production time and its minimization for allowed values of cutting depth and feed rate have been performed. Table 1 shows matrix results of the obtained optimization for the minimization of the production time by GA. For each depth of the cutting optimization process, the optimal cutting parameters are given. GA converges until the stopping criteria are meet, Figure 4. Presents the diagram of GA convergence.

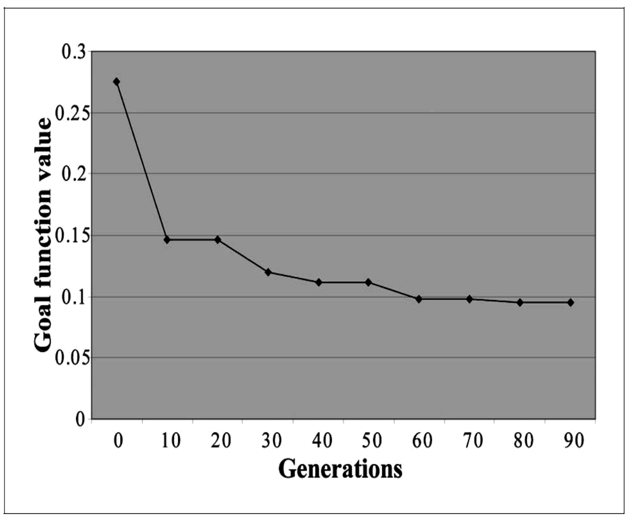

Figure 4. GA Convergence Graph

In the next step LP is applied. In the case shown above, the step of cutting depth increase has been 0.5 mm. The LP chose depths of 4 mm and 5 mm that have given the shortest machining time of 16.86 s for total roughing depth of 9 mm. On this simplified model, we have been able to implement the procedure of the defining a technological machining parameters for the specific product geometry, fast and with high accuracy. This type of the proposed solution gives a possibility for automatic selection of the machining parameters and for simple implementation in CAPP systems, due to developed interfaces in our solution.

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Table 1. Optimal Cutting Parameters for Various Depths

Feed rate / m/rev	Cutting speed / m/min	Mach. time / s	Cutting power / kW	Cutting force F_z / N	Main spindle freq. n / min^{-1}	Cutting depth / mm
0.90	603	4.70	16.15	1608.18	3998	1
0.90	588	4.72	23.59	2405.80	3987	1.5
0.89	566	4.81	29.99	3178.94	3919	2
0.78	518	5.62	29.96	3467.89	3669	2.5
0.72	464	6.40	29.90	3864.34	3360	3
0.68	420	7.11	29.99	4286.21	3109	3.5
0.77	327	7.80	29.99	5509.45	2476	4
0.70	320	8.44	29.99	5629.99	2483	4.5
0.40	496	9.06	29.96	3621.02	3953	5

IV. CONCLUSION

This paper deals with a novel approach to optimization of the machining parameters (turning process), by basing on the use of artificial intelligence. The proposed model is combined between GA and implementation of binary linear programming optimization (LP). This methodology has been implemented to optimize the turning simple model process. The main advantage of proposed method is ability to perform multi-objective optimization, minimum machining time and minimum production cost, while considering technological and material constrains. The results obtained from the simulation model have presented a fast and suitable solution both to the automatic definition of the machining parameters and to possible implementation in CAPP systems. The simulation results have been confirmed by the experiment.

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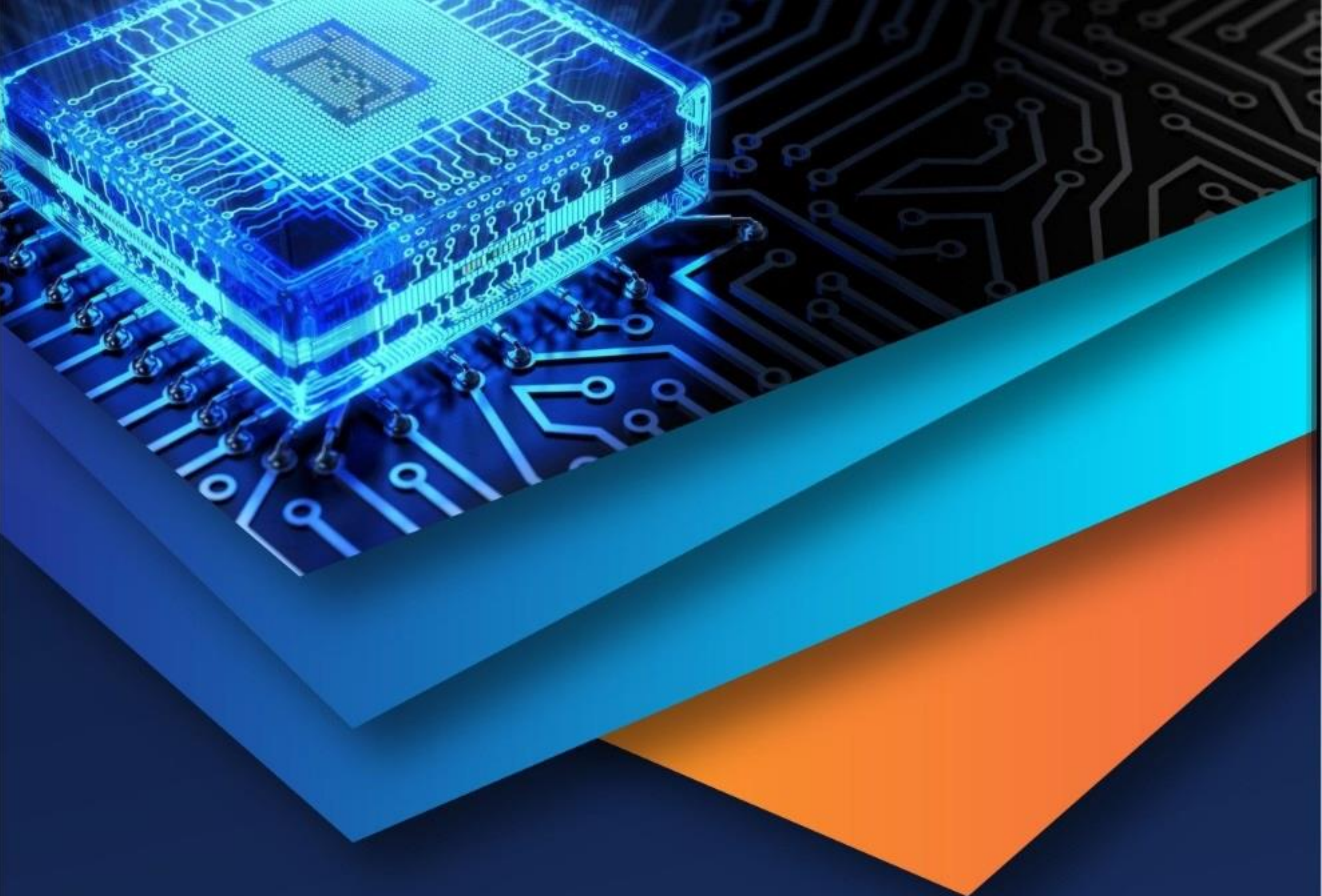
AUTHORS'S PROFILE

Abhishek Agrawal is currently PhD Scholar from University Institute of Technology, RGPV, Bhopal, India. He received the B.E. degree in Mechanical Engineering from the Government Engineering College, Ujjain, India, in 2007, and the M.Tech degree in Computer Integrated Manufacturing from the Samrat Ashok Technical Institute (SATI) Vidisha, India, in 2010. He has 6 years teaching experience from reputed institution of Madhya Pradesh. Also, he has published few research papers in reputed national and international journal.
His current research interests include CAD/CAM, CAPP, Machining Parameter Optimization and Genetic Algorithms.



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