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DEVELOPMENT OF COMPUTER AIDED PROCESS PLANNING (CAPP) FOR OPTIMIZATION OF MACHINING PARAMETERS USING A GENETIC ALGORITHM APPROACH

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Abstract: *This paper presents the application of genetic algorithms (GAs) in computer aided process planning (CAPP), and the development of a CAPP system based on a Genetic Algorithm, for optimizing the machining parameters of milling operations. An objective function based on maximum profit is used, while considering the practical constraints, such as acceptable feed rate and speed, surface finish, machine power, and cutting speed permit by the rigidity of the machine tool. An example is chosen from the available literature for comparing the results of the proposed technique with other handbook recommendations.*

Keywords: *Milling; Optimization. Genetic Algorithm; Milling operations; machining parameters; CAPP*

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1. INTRODUCTION

In today's manufacturing environment, many industries are adopting flexible manufacturing systems (FMS) to meet ever-changing competitive market requirements. To enhance the quality of machining products, and to reduce the machining costs and to increase the production rate, it is very important to select the optimal machining parameters, particularly where machines in comparison with conventional machines, there is a need to operate them as efficiently as possible in order to obtain the referred payback.

The selection of cutting conditions in machining operations has often relied on experience and handbook recommendations. The cutting parameters set by such practices are too far from even optimal. Therefore, a mathematical approach has received great attention as a technique for obtaining optimized machining parameters.

For the optimization of a machining process, either the maximum profit rate or the minimum production time is used as the objective function subject to the practical constraints. Some of the methods that have been used to solve machining problems are linear programming, geometric programming and the graphical method [1–4]. But many of them are restricted to turning operations only. Very few researchers have concentrated on multi-tool operations. Wang and Armarego [5] have suggested a method to optimize the machining parameters for milling operations. But this is restricted to only face milling operations. Similarly, other methods like genetic algorithms [6], Scatter search [7] and the simulated annealing algorithm [8] have been used to solve face milling operations. Some researchers have considered power as the only constraint and ignored the other constraints, such as cutting force, tool life and surface finish.

Tolouei-Rad and Bidhendi [9] have carried out significant work on the optimization of multi-tool milling operations. The method of feasible directions is used to solve the problem. Recently, this problem has been solved by Tabu search, the continuous ant colony algorithm and particle swarm optimization to obtain more accurate results [10].

In the present work, the Genetic Algorithm (GA), one of the recently emerged optimisation techniques in the area of metaheuristics, is applied successfully to optimise the parameters of multi-tool milling operations. The search mechanisms used in GA result in optimisation procedures with the ability to escape local optimum points. The advantage with this approach is that it can be used for solving a diverse array of complex optimisation problems [11, 12]. The results exhibit the efficiency of the GA over other methods.

2. MATHEMATICAL MODEL

The mathematical model developed by Tolouei-Rad and Bidhendi [9] is considered in this work. GA is applied to optimize machining parameters for multi-tool milling operations involved in machining a work piece by a CNC machining centre. The maximum profit rate is considered as the objective function. The optimal values is obtained for each tool from the each pass. The depth of cut is taken as the maximum permissible depth for a given work piece and cutting tool combination. Therefore, the problem of determining the machining parameters is reduced to determining the proper cutting speed and feed rate combination. An example is taken from the literature [9] for comparing the results obtained by GA with other methods.

2.1 Objective Function

The objective function is to maximise the total profit rate, and can be determined by:

$$P_r = \frac{S_p - C_u}{T_u} \tag{1}$$

The unit cost can be represented as:

$$C_u = c_{mat} + (c_l + c_o)t_s + \sum_{i=1}^{m}(c_l + c_o)K_{li}V_i^{-1}f_i^{-1} + \sum_{i=1}^{m} c_{ti}K_{3i}V_i^{(1/n)-1}f_i^{[(w+g/n)]-1} + \sum_{i=1}^{m}(c_l + c_o)t_{tci} \tag{2}$$

The unit time required for producing a part in the case of multi-tool milling can be defined as:

$$T_u = t_s + \sum_{i=1}^{m} K_{1i}V_i^{-1}f_i^{-1} + \sum_{i=1}^{m} t_{tci} \tag{3}$$

2. 2 Constraints

In practice, the possible ranges for the cutting speed and feed rate are limited by the following constraints:

1. Maximum machine power
2. Surface finish requirement
3. Maximum cutting force permitted by the rigidity of the tool

4. Available feed rate and spindle speed on the machine tool

2.2.1 Power

The machining parameters should be selected in such a way that the maximum available machine power is utilized. The required machining power should not exceed the available motor power. Therefore, the power constraint can be written as:

$$C_5 V f^{0.8} \leq 1 \quad (4)$$

where,

$$C_5 = \frac{0.78 K_{\mathrm{p}} W z a_{\mathrm{rad}} a}{60 \pi d e p_{\mathrm{m}}} \quad (5)$$

2.2.2 Surface Finish

The required surface finish Ra should not exceed the maximum attainable surface finish Ra(at) under the practical conditions. Therefore, the surface finish of the face milling operation can be expressed by the following equation:

$$C_6 f \leq 1 \quad (6)$$

where,

$$C_6 = \frac{318[\tan(la) + \cot(ca)]^{-1}}{R_{\mathrm{a(at)}}} \quad (7)$$

and for end milling:

$$C_7 f^2 \leq 1 \quad (8)$$

where,

$$C_7 = \frac{318(4d)^{-1}}{R_{a(at)}} \quad (9)$$

2.2.3 Cutting Force

The total cutting force Fc resulting from the machining operation should not exceed the permitted cutting force Fc(per). The permitted cutting force for each tool is considered as its maximum limit for cutting forces. Therefore, the cutting force constraint becomes:

$$C_8 F_{\mathrm{c}} \leq 1 \quad (10)$$

Where

$$C_8 = 1/F_{\mathrm{c}}(per) \quad (11)$$

2.2.4 Speed Limits

1. Face milling: 60–120 m/min
2. Corner milling: 40–70 m/min
3. Pocket milling: 40–70 m/min
4. Slot milling 1: 30–50 m/min
5. Slot milling 2: 30–50 m/min

2.2.5 Feed Rate Limits

1. Face milling: 0.05–0.4 mm/tooth
2. Corner milling: 0.05–0.5 mm/tooth
3. Pocket milling: 0.05–0.5 mm/tooth
4. Slot milling 1: 0.05–0.5 mm/tooth
5. Slot milling 2: 0.05–0.5 mm/tooth

3. METHODOLOGY

Most of researchers have used traditional optimization technique for solving machining problems. The traditional methods of optimization and search do not fare well over a broad spectrum of problem domains. Recently many authors have been trying to bring out the utility and advantage of non-traditional optimization techniques, such as genetic algorithm. In this paper it is proposed to use the new evolutionary Genetic algorithm approach for the machining optimization problem. Upon development of the optimization model and its constraints, the Genetic algorithm approach should be employed to solve the problem. The optimization model adopted in this work is a nonlinear, multi-variable and multi-constraints model of a complex nature.

3.1 Genetic Algorithm

In GA the candidate solution is represented by a sequence of numbers known as chromosome or string. A chromosome’s potential as a solution is determined by its fitness function, which evaluates a chromosome with respect to the objective function of the optimization problem under consideration. A judiciously selected set of chromosomes is called a population & population at a given time is a generation. The population size remains fixed for generation to generation and has a significant effect on performance of GA. GA’s operates on a generation and consist of three main operations: -

1. Initialization: - Randomly generate a population, which satisfies all the (manufacturing) constraints.

2. Fitness Evaluation: - Calculate the fitness value for each string from precedence cost matrix (PCM).

3. Reproduction: - Selection of copies of chromosome proportional to their fitness value.

4. Crossover: - An exchange of sections of chromosomes.

5. Mutation: - A random modification of chromosome.

The chromosome resulting from these operations, often known as offspring or children, from the next generation's population. The process is repeated for a desired number of generations, usually up to a point where the system converges to a significant well performing sequence.

3.2 Implementation of GA

Binary coding is used in this work to represent the variables depth of cut and feed rate. The length of string is usually determined according to the desired solution accuracy. Here 10 bits are chosen for depth of cut and feed rate. The strings (00000000) and (11111111) would represents the points lower and upper limits for depth of cut and feed value. The GA operates on a generation and consists of three main operation described above.

The following parameter are used in the GA

Sample size	30
Crossover probability	0.6
Mutation probability	0.05
Number of generation	100

3.3 Result of the Genetic Algorithm

The following table shows the result of the genetic algorithm for 20 iterations. From the above graph, it is evident that the maximum profit rate is observed at 20th iteration. The rise of curve is due to a local optimum. The profit rate is gradually increasing up to end of the iteration. Table 4 represents unit cost, unit time and total profit rate resulting from all the machining operation required to produce the product. These values have been determined based on optimum machining parameters and are compared with those resulting from the method of feasible direction and handbook recommendation.

Table 3. Best GA profit rate

Speed (V) (m/min)	Feed (f) (mm/tooth)	Unit Cost (Cu) (Rs)	Unit Time (Tu) (min)	Profit rate (Pr) (Rs/min)
119.942	0.264			
41.641	0.255			
40.558	0.401	582.9	4.231	3.691
31.018	0.446			
44.312	0.362			

4. CASE STUDY

The component shown in Fig. 2 is to be produced on a CNC machining centre [9]. The work piece requires four machining features: step, pocket and two slots. Different tools are needed to machine these features. The front view and the top view of the part with its dimensions are shown in Fig. 3.

The objective is to determine the cutting conditions of each feature so that the part can be machined with the maximum profit rate. The specifications of the machining centre, material and values of constants are given below [9]:

– Machine tool data: Vertical CNC machining centre,

Pm = 8.5 KW, e = 95%

– Material data: 10L50 leaded steel, hardness =225 BHN

– Constants: Sp Rs. 1550

Cmat Rs. 31

Co Rs. 1.45 per min

C1 Rs. 0.45 per min

Table 4. Comparison of unit cost, unit time and profit rate

Sl. No.	Unit cost Cu	Unit Time Tu	Profit rate Pr
1. Handbook	Rs. 1138.94	9.39 min	0.72/min
2. Method of feasible direction	Rs. 704.32	5.47 min	2.5/min
3. Genetic algorithm	Rs. 582.92	4.230 min	3.688/min
Improvement over handbook	Rs. 554.9	5.173 min	2.978/min
Improvement over method of feasible direction	Rs. 121.024	1.253 min	1.201/min
Improvement (handbook)	48.8%	56%	419%
Improvement (method of feasible direction)	17.2%	22.9%	49%

5. RESULTS AND COMPARISON

Table 3 exhibits the optimal cutting parameters for each operation, unit cost, unit time and the profit rate obtained by GA.

The comparison of results is shown in Table 4. The improvement in profit rate determined by GA is compared with the other methods. From the table, it is observed that GA has obtained an improvement of 419%, 49% over the handbook recommendation, method of feasible directions respectively. GA has found the best result over all of the other methods.

6. CONCLUSION

Although several conventional optimization techniques have been applied to solve machining problems, their application is often limited because of the probability of getting stuck at local–optimal points and the lack of robustness. Since so much complexity is involved in machining optimization problems, the application of metaheuristic is inevitable. Genetic algorithm (GA) is one of the recently optimization techniques developed in the area of metaheuristic. The search mechanisms used in GA result in optimization procedures with the ability to escape local optimum points. The highly promising outcome of this study suggests that GA can be a very useful tool for optimization of machining conditions. Similar to other metaheuristic, such as simulated annealing and Scatter search, GA is a generalized optimization methodology for machining optimization problems, since it has no restrictive assumptions about the objective function and constraint set. Furthermore, as observed in the present study, GA can obtain superior solutions to other metaheuristic. This approach can be extended to optimize the parameters of other machining processes, such as drilling and unconventional machining processes.

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