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Optimization of Machining Parameters in Turning Operation by Evolutionary Technique

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Abstract: This paper presents the procedure to obtain the machining conditions for turning operation. Considering unit cost of production as an objective function. The optimality conditions for single point cutting operation are determined based on objective function. Machining conditions are obtained for minimum cost incorporating various important cost related machining criteria such as machining cost, tool life, tool changing time etc. An example illustrates the optimization by population based Genetic Algorithm.
Keywords: Genetic algorithm, cost, tool life, feed rate, depth of cut, cutting speed.

LIST OF ABBREVIATIONS

C Constant in tool life equation
CI Machine idle cost due to loading and unloading operations and tool idle time (Rs/pc)
CM Cutting cost by actual time in cutting (Rs/pc)
CR Tool replacement time cost (Rs/pc)
CT Tool cost (Rs/pc)
D Diameter of work piece (mm)
d Depth of cut in machining (mm)
d_C Total depth of cut to be removed in machining (mm)
f Feed in turning and facing operation (mm/rev)
h_1, h_2 Constants relating to cutting tool travel and approach/depart time (min).
K_0 Direct labour cost + overhead (Rs/min)
K_t Cutting edge cost for turning & facing (Rs/min)
L Length of work piece (mm)
N Spindle speed in rpm
n Number of passes during the machining
T Tool life (min)
T_M Time taken in machining in min.
T_L Time taken in loading and unloading in min.
T_R Tool replacement time per tool failure in min.
T_T Total time taken in machining in min.
t_e Time required to exchange a tool (min/edge)
t_p Preparation time such as loading and unloading time (min)
t_R Tool replacement time (min)
UC Unit production cost for turning except material cost (Rs/pc)
V Cutting speed in machining (m/min)
α, β, γ Constants in tool life equation
GA Genetic algorithm

I. INTRODUCTION

In today's manufacturing environment, to ensure the quality of the machining products, to reduce the machining costs, and to increase the machining effectiveness, it is very important to select the machining parameters when the machine tools are selected in computer numerical controlled (CNC) machining. The main objective in machining is to produce products with low cost but with high quality. Cost consciousness with respect to the metal cutting process is an essential element in efficient manufacturing. So, it is essential to analyze the metal cutting operations to operate at economic conditions. Due to high capital cost and machining cost of CNC machines, there is an economic need to operate machines as efficiently as possible in order to obtain the required payback. The success of the machining operation mainly depends on the selection of machining parameters such as cutting speed, feed, and depth of cut.

Y. C. Shin et al. [1] have presented a model for multi-pass turning, and dynamic programming was used for selection of depth of cut for individual passes. Bob White et al. [2] have added the quality cost of the part as an important element to the machining cost. This model determines the effect of surface roughness on the production cost. Chen et al. [3] have developed an optimization model for a continuous profile using simulated annealing approach. In this machining model, straight turning, taper turning, and circular turning were simultaneously considered. P. K. Kee [4] has studied the development of constraint optimization analysis and strategies for selecting the optimum cutting conditions for multi-pass rough turning operations in CNC, and conventional lathe was outlined and discussed. Bhaskara Reddy et al. [5] have used genetic algorithm to select optimal depth of cut to achieve minimum production cost in multi-pass turning operations. M. C. Chen et al. [6] have developed an optimization model for a continuous profile using simulated annealing approach. In this machining model, straight turning, taper turning, and circular turning were simultaneously considered. James Kennedy et.al. [7] have developed particle swarm optimization which is a population-based search procedure that could yield global optimum solution. Y. V. Hui et al. [8] have developed a time dynamic economic model for a single pass turning operation. This literature provided a quality machining economical model for turning to investigate the trade-off between quality cost and other cost factors. G. C. Onwubolu et al. [9] implemented genetic algorithm for the determination of the cutting variables in multi-pass machining operations. The depth of cut constrained for the multi-pass turning was not considered. K. Choudhri et al. [10] have also suggested genetic algorithm to find the optimum machining conditions in turning. In this work, two objective functions, namely unit production time and unit production cost, were optimized after satisfying few practical constraints. Vijayakumar et al. [11] have applied ant colony algorithm to find optimal machining parameters for multi-pass turning operation and also found that the proposed algorithm out per formed the adopted genetic algorithm. Saravanan et al. [12] have developed a new model based on genetic algorithm and simulated annealing for optimizing machining parameters for turning operation. Zhang Li Ping et al. [13] have used particle swarm optimization technique to find out optimal choice of machining parameters.

II. PROPOSED METHODOLOGY

Non-traditional search and optimization methods are becoming very popular in engineering optimization problems. These techniques mimic the process of natural evolution by adopting the method of survival of the fittest among a structured solution by information exchange. The non-traditional optimization method Genetic Algorithm is used in this work as follows:

A. Concept of Genetic Algorithm

Genetic algorithms are search algorithms based on the mechanics of natural selection and natural genetics. The genetic algorithm is a probabilistic technique that uses a population of design rather that a single design at a time. It is analogous to natural selection in the evolution of living organisms in that the fittest members in the population have a better chance to survive, reproduce and thus transfer their genetic material to the successive generations. The initial population is formed by a set of randomly generated members. Each generation consists of members whose constituents are the individual design variables that characterize a design and these are embedded in a binary string. Each member is evaluated using the objective function and is assigned a fitness value, which is an indication of the performance of the other members in the population. A biased selection depending on the fitness value decides which members are to be used for producing the next generation. The selected strings (a new set of artificial creatures) are the parents for the next generation which evolves from the use of two genetic operators namely crossover and mutation. These operators takes two parents strings, splits them at a random location, a new population of designs. The new strings formed are evaluated and the iteration continues until a maximum number of generations has been reached or until a user defined termination criteria has been met.

Figure shows the sequence of steps in a basic genetic algorithm. The control parameters that have been initially specified are the population size the crossover and the mutation probabilities the maximum number of generations and the termination criteria. There are many alterations that may have to be introduced into the basic genetic algorithm described above, depending upon the problem. For example the whole population can be used for reproduction (generational replacement), only a part of the population can undergo reproduction (steady state replacement) or the best member in the population can be passed on to the next generation without any changes (elitist selection). The crossover operator can occur at a single point or at more than one point (multi point crossover). The fitness function may be based on the objective function, value or on the position of the member in the population (linear normalization). The control parameters of the genetic algorithm any be fixed at a particular value of can be made to vary as the genetic algorithm progresses. There is no single variation that out performs the other for all types of they may be mapped to a designer has to decide as to which variation to implement.

B. *Parameters of GA*

Number of iteration performed	54
Population	100
Cross-over probability	0.80
Mutation probability	0.05

III. SINGLE PASS TURNING OPERATION

A. *Mathematical Model*

This work is concerned with the optimal selection of machining parameters such as cutting speed, feed rate, and depth of cut. Since these parameters strongly affect the cost, time, productivity, and quality of the machined parts, determining the optimal machining parameters is an essential step in machining operation. The objective is a combined objective function that includes minimum production time and minimum production cost.

B. *Formulation of Objective Function*

The values for the machining parameters like L, D, Nmin, Nmax, etc. are obtained from the knowledge of the machine limitations and from the handbooks. The tool material is tungsten carbide, and the work piece material is high carbon steel. The values of machining parameters for single pass turning operation are shown in Table 1.

1) *Production Cost*

The unit production cost is the sum of cutting cost (machining cost) (C_M), machine idle cost (C_I), tool replacement cost (C_R), and tool cost (C_T) etc including overhead cost excluding material cost,. The fundamental form of the unit cost (i.e. objective function) can be expressed as.

Tool replacement cost for each part is calculated based on the machining time of the part to the tool life. This is because a single tool may be used to machine several parts before it needs to be replaced by a sharp one.

Table 1 Values of machining parameters

Parameters	Values	Parameters	Values
L	300 mm	t_p	0.75 min/edge
D	50 mm	C	1686145.34
Nmin	220 rpm	h_1	$7 \times (10)^{-4}$
Nmax	800 rpm	h_2	0.3
fmin	0.044 mm/rev	K_0	30.85 Rs/edge
fmax	0.132 mm/rev	K_t	154.25 Rs/edge
dmin	0.4 mm	α	1.7
dmax	1.2 mm	β	1.55
t_e	1.5 min/edge	γ	1.22

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2) Unit Production Cost except material cost in turning

UC = cutting cost (machining cost) + machine idle cost + tool replacement cost + tool cost

$$UC = C_M + C_I + C_R + C_T \quad (1)$$

$$= K_0 (T_M + T_L + T_R) + (K_t / T) T_M \quad (2)$$

= (direct labour cost+ overhead) [feed engagement or machining time + work piece loading unloading time or machine idle time + tool replacement time per tool] + tool cost (3)

$$T_M = \frac{L}{f \times N} \times n \quad (4)$$

work piece loading unloading time or machine idle time = T_L

= [preparation time for loading/unloading + constant related to tool travel & approach time (min) x length of workpiece + constant related to tool travel & departure time (min)] x (number of passes +1) (5)

$$= t_p + (h_1 L + h_2)\, x(n+1) \quad (6)$$

tool replacement time per tool = T_R

$$T_R = \frac{\text{Time required to exchange a tool x Machining time}}{\text{Tool life}} \quad (7)$$

$$= \frac{t_e}{T} \times T_M \quad (8)$$

Tool life is given by:

$$T = \frac{C}{V^{\alpha} f^{\beta} d^{\gamma}} \quad (9)$$

$$\text{tool cost} = \text{Tool cost per failure} \times \frac{\text{Machining Time}}{\text{Tool Life}} \quad (10)$$

$$= K_t \frac{T_M}{T} \quad (11)$$

$$UC = K_0 (T_M) + K_0 (T_L) + K_0 (T_R) + (K_t / T) T_M \quad (12)$$

$$UC = 38.871 + n[15.7335 + 9255x(N)^{-1} (f)^{-1} + 1.533905357 \times (10)^{-3} x(N)^{0.7} x(f)^{0.55} x(d)^{1.22}] \quad (13)$$

C. Machining Parameters

Although there are many machining parameters which affect the machining operation, cutting speed, feed, and depth of cut have the greatest effect on the success of a machining operation. Therefore, only these machining parameters are considered in this work. Moreover, these machining parameters also considered as the practical constraints.

1) Cutting speed

When compared to depth of cut and feed rate, cutting speed has a greater effect on tool life. Certain combinations of speed, feed, and depth of cut are usually selected for easy chip removal, which are directly proportional to the type of tool and work piece material. Thus, the range of cutting speed can be written as:

$$v_{min} \le v \le v_{max} \quad (14)$$

2) Feed

By increasing the feed and decreasing the cutting speed, it is always possible to obtain much higher metal removal rates without reducing tool life. Thus, the range of feed can be written as:

$$f_{min} \le f \le f_{max} \quad (15)$$

3) Depth of cut

Selection of depth of cut should counter balance between the tool life and metal removal rate to obtain highest permissible level of depth of cut. Thus, the range of depth of depth of cut can be written as:

$$d_{min} \le d \le d_{max} \quad (16)$$

D. Physical constraints

There are always many constraints that exist in the actual cutting condition for the optimization of the objective function. For a given pass, an optimum cutting speed, feed, and depth of cut is chosen and, thus, balancing the conflict between the metal removal rate and tool life. The following constraints are considered in optimizing the machining parameters. On satisfying these constraints, the optimum machining parameters are arrived.

1. Parameter constraints

$$v_{min} \leq v \leq v_{max},\ f_{min} \leq f \leq f_{max}\ \&\ d_{min} \leq d \leq d_{max} \qquad (17)$$

E. Results of GA

The minimized COF value and corresponding machining parameters values of cutting speed, feed, and depth of cut are given below in Table 2.

Machining parameters		
N	f	d
rpm	mm/rev	mm
739.182	0.131	0.413
Objective function		
Unit Production Cost except material cost in turning in	Rs/piece	
	149.88	

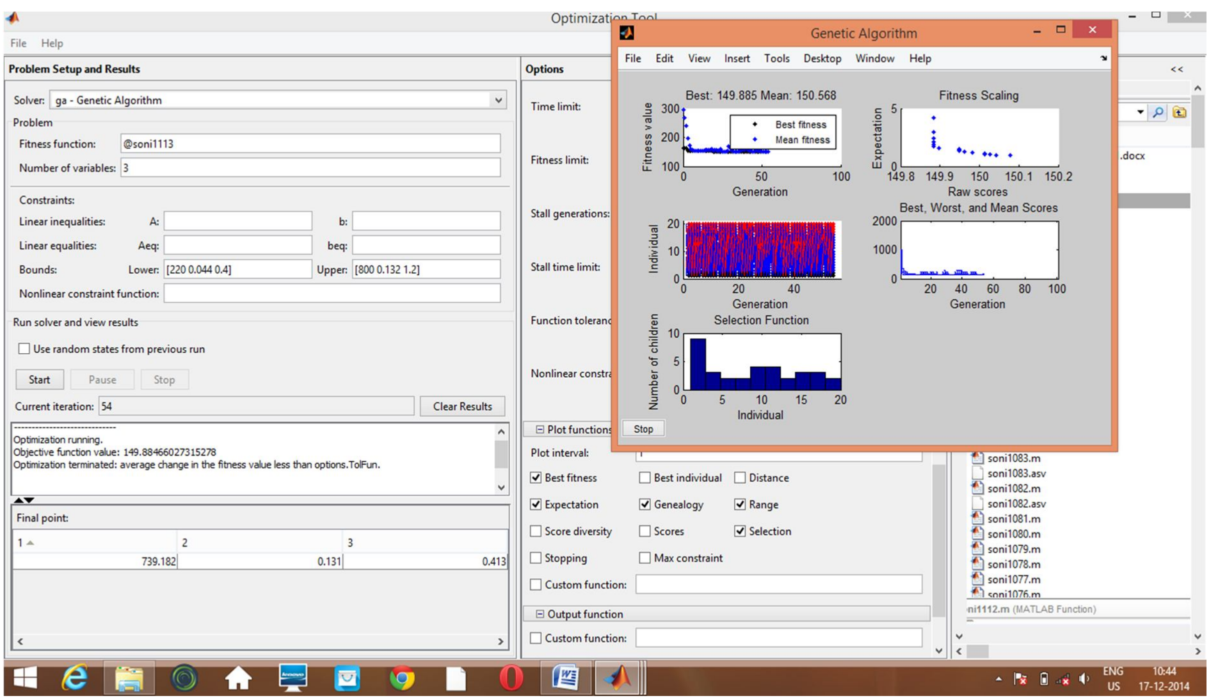

Fig. 2 Display of Results on using MATLAB software for Optimization using Genetic Algorithm Toolbox

IV. CONCLUSION

In this work, the mathematical models of turning machining operation is considered for optimization. The objective function is to minimize the unit production cost except material cost in turning and the machining parameters are cutting speed, feed, and depth of cut. The non-traditional optimization techniques such as genetic algorithm optimization is used to optimize machining parameters with the application of MATLAB Software. The software is completely generalized and problem independent, so that it can be easily modified to optimize any machining operation under various economic criteria and numerous practical constraints. Moreover, all the non-traditional techniques can be easily used to implement for other engineering applications.

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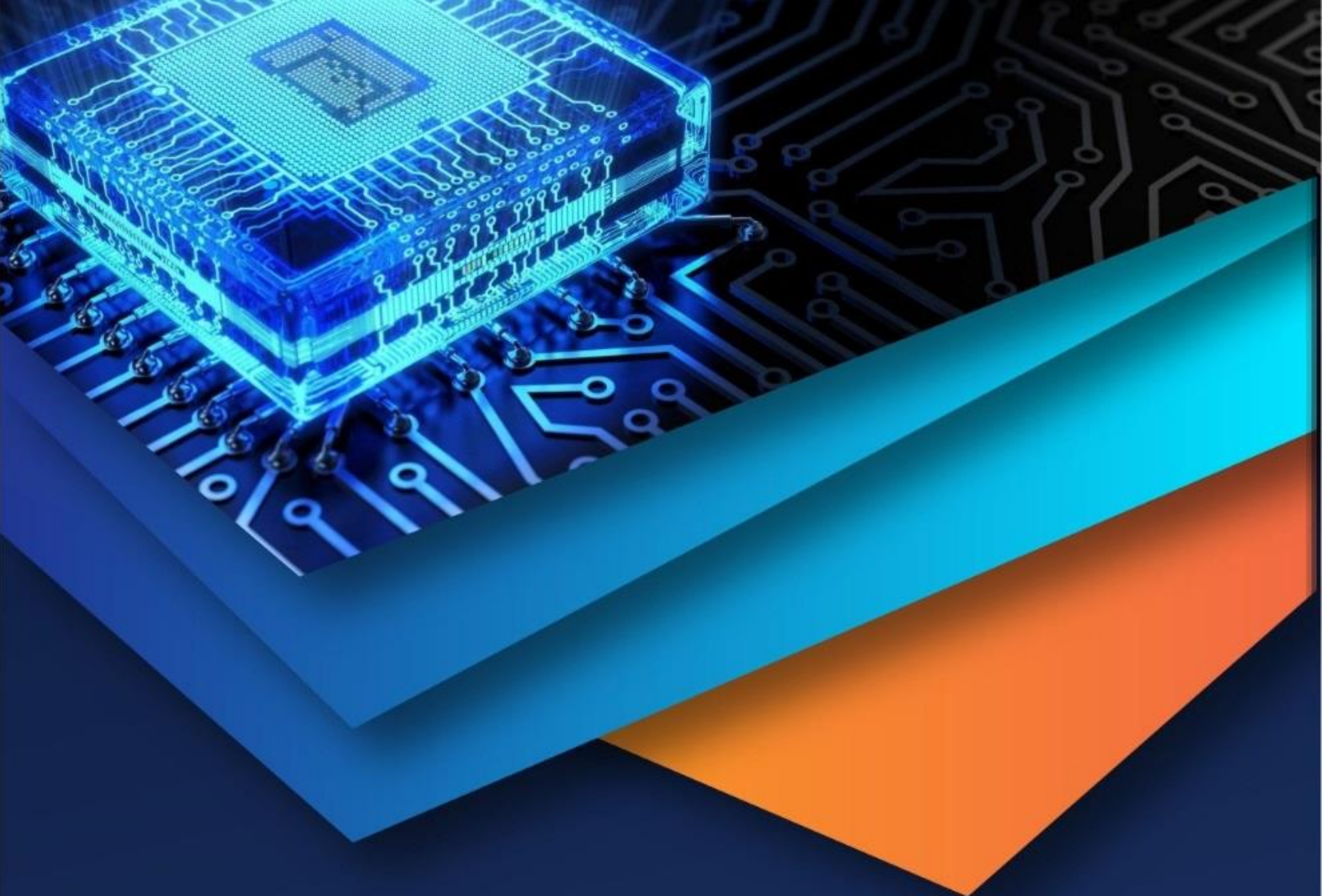

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