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OPTIMIZATION OF MACHINING PARAMETERS USING BIO-GEOGRAPHY BASED ALGORITHM TECHNIQUE

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ABSTRACT

This paper, proposes a non-linear constrained mathematical model to search the optimal cutting parameters such as cutting speed, feed rate and depth of cut. The model deal with the multi-pass turning operation which is comprises of multi-pass rough machining and finish machining. An optimization technique based on bio-geography based optimization has been introduced to optimize the multi-pass roughing and single-pass finishing parameters to achieve minimum production cost. BBO is very effective and efficient method for optimization problem. An example is adopted from the literature to solve the proposed optimization problem.

KEYWORDS: Multi-Pass Turning Operation, Cutting Parameters, Bio-Geography Base Optimization

INTRODUCTION

Nomenclature

UC Unit production cost except material cost ($/piece)

C_M Cutting cost by actual time in cut ($/piece)

C_I Machine idle cost due to loading and unloading operations and idle motion time ($/piece)

C_R Tool replacement cost ($/piece)

C_T Tool cost ($/piece)

V_r, V_s Cutting speed in rough and finish machining (m/min)

V_{rL}, V_{rU} Lower bound and upper bound of cutting speed in rough machining (m/min)

V_{sL}, V_{sU} Lower bound and upper bound of cutting speed in finish machining (m/min)

f_r, f_s Feed rates in rough and finish machining (mm/rev)

f_{rL}, f_{rU} Lower bound and upper bound feed rates in rough machining (mm/rev)

f_{sL}, f_{sU} Lower bound and upper bound feed rates in finish machining (mm/rev)

d_r, d_s Depth of cut for each passes of rough and finish machining (mm)

d_{rL}, d_{rU} Lower bound and upper bound depth of cut for each passes of rough machining (mm)

d_{sL}, d_{sU} Lower bound and upper bound depth of cut for each passes of finish machining (mm) n Number of rough cuts (an integer)

d_t Depth of material to be removed (mm)

D,L Diameter and length of work –piece (mm)

k_o Direct labor cost + overhead (\$/min)

k_t Cutting edge cost (\$/edge)

t_{mr},t_{ms},t_m Rough, finish and actual machining times (min)

t_e,t_r Tool exchange and tool replacement times. (min)

h_1,h_2 Constants related to tool travel and approach / departure time (min)

T,T_r,T_s Tool life, expected tool life for rough machining, expected tool life for finish machining (min)

T_p Tool life of weighted combination of T_r and T_s (min)

T_L,T_U upper and lower bounds for tool life (min)

p,q,r,C_o Constants of tool life equation

F_r,F_s Cutting forces during rough and finish machining (Kgf)

k_1,μ,v Constants of cutting force equation

P_r,P_s Cutting power during rough and finish machining (KW)

P_U Maximum allowable cutting power (KW)

SC Limit of stable cutting region constraint

Q_r,Q_s Chip tool interface rough and finish machining temperatures (C^o)

Q_U Maximum allowable chip tool interface temperature (C^o)

OBJECTIVE

Optimization has become very important in this competitive world. In any field we can observe that optimization has become a key point to success. In this paper, optimization of turning operation is done. Turning process is the most common machining process for cutting operation. The process of metal removal using turning operation comprise of two stages e.g. rough machining stage and finish machining stage. Several variables such as feed rate, cutting speed, depth of cut, work material, its properties and characteristics of output variables such as production cost, production time, no of iteration, tool life, surface roughness, temperature, cutting force etc. should be considered to get the final products that meet the specification. Many traditional mathematical programming techniques have been used to solve optimization problems, but these techniques had so many drawbacks. These techniques couldn’t solve the multimodal problems as they give only local optimal solutions and cannot solve the problem having so many constraints. Metaheuristic techniques such as particle swarm optimization, genetic algorithm, ant colony algorithm, evolutionary algorithm, bio-geography based algorithm are being utilized to solve these optimization problems. In this paper, Bio-geography based algorithm is being used to optimize the cutting parameters of multi-pass turning process. Bio-geography based optimization is a nature based algorithm. BBO is the study of geographical distribution of biological organism such as animal, plants over time and space. The main objective of this process planning is to find the appropriate cutting parameters which can provide max profit to the company and could be available to the customer with appropriate quality and lead time. Crookall and Venkataramani[1] studied the optimization technique for the turning operation.

A probabilistic approach has been developed to the determination of the optimum cutting conditions. But in this paper constraints are not considered. Then, Shin. Y. C. and Joo Y.S.[3] Optimize the machining conditions with practical constraints. They proposed the mathematical formula to optimize the cutting parameters by dynamic programming approach. Then, Onwubolu and Kumalo [4] approach with Optimization of multipass turning operations by genetic algorithms. They optimize the same problem using Genetic algorithm and proved more efficient as compare to the Simulated Annealing. Vijayakumar [5] use Ant Colony algorithm to optimize and proved their method give better result with less iteration and within short time. They compare their result with other algorithm, and come to a conclusion that ACO is very effective method. Wang YC. [6] works on optimization of Ant colony algorithm and find that paper of vijaakumar[5] where he did not prove the optimal values they found for the depth of the rough cuts and the finishing cut and the constraint related to the no of cuts. Abderrahim, and imane [7]optimize the cutting parameters by newly developed firefly optimization technique. Tsai [12] came with simulated annealing approach for optimization of multi-pass turning operations They solve the optimization problem using same mathematical formulae by Simulated Annealing algorithm. This algorithm giving less production cost but the time consumption is more than other.

The algorithm is considered in the continuous constraints optimization problem where the task is to minimize the production cost. The researcher compared with other algorithm such as genetic algorithm, simulated annealing and found that the result obtain near optimal values. In this paper, Bio-geography Based optimization technique (BBO) is used to optimize the multipass turning operation. We are using the same mathematical formulation given by Shin, Y, C., and Joo, Y.S.(3)

MULTI-PASS TURNING MODEL

The main objective of the paper is to find the optimal cutting parameter including cutting speed, feed rate, depth of cut, number of rough cuts and no of iteration in order to minimize the unit production cost and simultaneously achieve a good surface finish considering certain constraints such as roughness, power etc. The mathematical model used by Chen and Tsai [12] is preferred adapted to find the optimal machining parameters.

Cost Function

The unit production cost, *UC*, for the multi-pass turning operations problem consist of four components.

- Machining cost by actual time in cutting operation, $C_{M.}$
- Machine idle cost due to loading and unloading operations and idle tool motion, $C_{I.}$
- Tool replacement cost, C_R.
- Tool cost, C_T

Unit Production Cost

Using equations (1), (2), (3) and (4), the unit production cost, *UC*, is defined as:

$UC = C_M + C_I + C_R + C_T$;

$$UC = k_0\left[\frac{\pi DL}{1000 V r f r}\left(\frac{dt-ds}{dr}\right) + \frac{\pi DL}{1000 V s f s}\right] + {}_0\left[t_c + (h_1 L + h_2)\left(\frac{dt-ds}{dr} + 1\right)\right] + \qquad (5)$$

$$k_0 \frac{te}{Tp}\left[\frac{\pi DL}{1000 V r f r}\left(\frac{dt-ds}{dr}\right) + \frac{\pi DL}{1000 V s f s}\right] + \frac{Kt}{Tp}\left[\frac{\pi DL}{1000 V r f r}\left(\frac{dt-ds}{dr}\right) + \frac{\pi DL}{1000 V s f s}\right]$$

Surface Quality Function

The surface quality function is described as:

$$R_a k v_s^{x1} f_s^{x2} d_s^{x3} \qquad (6)$$

Where x_1,x_2,$x_3$and k are the constants relevant to specific tool- work piece combination. Since reaching an idle surface finish is not necessarily required in industry, so in this paper surface quality function is treated as a constraint and therefore constraint satisfaction method is adopted

Cutting Condition Constraints

Several cutting constraints are considered during roughing and finishing operations as follows:

- Parameter bounds
- Tool-life constraint
- Cutting force constraint
- Power constraint
- Surface finish constraint
- Stable cutting region constraint
- Chip-tool interface temperature constraint
- Surface finish constraint (for finishing stage only)
- Roughing and finishing parameter relations
- Depth of cut equality constraint.

Roughening Machining

- **Parameter Bounds**

Due to the limitations on the machine and cutting tool and due to safety of machining the cutting parameters are limited with the bottom and top permissible limit:

Cutting speed: $V_{rL} \leq V_r \leq V_{rU'}$

Feed rate: $f_{rL} \leq f_r \leq f_{rU}$ (7)

Depth of cut: $d_{rL} \leq d_r \leq d_{rU}$

- **Tool-Life Constraints**

The constraint on the tool life is taken as

$T_L \leq T_r \leq T_U$ (8)

- **Cutting Force Constraint**

The maximum amount of cutting forces should not exceed a certain value as higher forces produce shakes and vibration.This constraint is given by

$F_r = k_1 (f_r)^{\mu} (a_r)^{\upsilon} \leq F_u$ (9)

- **Power Constraint**

The nominal power of the machine P_U limits the cutting process

$P_r = \frac{FrVr}{6120\eta}$ (10)

Efficiency $\eta = 0.85$

- **Stable Cutting Region Constraint**

This constraint is given by

$(V_r)^{\lambda} (f_r)(d_r)^{\mu} \geq SC$ (11)

- **Chip Tool Interface Temperature Constraint**

The temperature generated during the cutting operation should not exceed the permissible limit. It is expressed as;

$Q_r = k_2 (V_r)^{T} (f_r)^{\phi} (d_r)^{\delta} \leq Q_U$ (12)

Finish Machining

All the constraint other then the surface finish constraint are similar for rough and finish machining

- **Surface Finish Constraint**

The surface finish constraints is given by:

$\frac{fs}{8R} \leq (SR)_U$ (21)

The cutting parameter relation constraints are:

$V_S \geq k_3 V_r$ (22)

$f_r \geq k_4 f_s$ (23)

$d_r \geq k_5 d_s$ (24)

- **The Number of Rough Cuts**

The possible number of rough cuts is

$$n=\frac{dt-ds}{dr} \quad (25)$$

The restriction is:

$$\frac{dt-dsl}{drl} \le \frac{dt-ds}{dr} \le \frac{dt-dsU}{drU} \quad (26)$$

The optimization problem in multipass turnings can be divided into $m=(n_U-n_L+1)$ sub problems, in each of which the number of rough cuts n is fixed. So the solution of the whole optimization problem is divided into searching the optimal result of m sub problems and the minimum of them is the objective of the whole optimization problem.

BIO-GEOGRAPHY BASED OPTIMIZATION

Bio-geography based optimization [10] is the advance of evolutionary algorithm used for searching global optima. It is inspired by nature and is followed by immigration and emigration of species from one habitat to the other in search of rich habitats. The solution is represented by habitat with Habitat Suitability Index. This process is consists of two process migration and mutation.

In migration process, many parents contribute to a single offspring. Migration is used to change the existing solution and modify the solution. Migration is the probabilistic process that adjusts the habitats X_i. The probability is modified w.r.t immigration rate and the source of modified probability comes from X_i proportional to the emigration rate and is expressed as:

$$\lambda=I(1-\frac{S}{Smax}) \quad (27)$$

$$\mu=\frac{ES}{Smax} \quad (28)$$

Where, I is the maximum possible immigration rate, E is maximum emigration rate, s is no of species, S_{max} is max no of speci

Mutation is the second stage of bio-geographical process. During mutation drastic change made to the HSI of habitat due to certain events. Mutation increases with diversity among the candidate size. Candidate solutions is depend on the mutation probability as given in below.

$$M(s)=(1-P_S)M_{max}/P_{max} \quad (29)$$

Where M_{max} is a user-defined parameters, P_s is the species count of the habitat, P_{max} is maximum species count. Mutation is done on the basis of mutation probability of each habitats and by replacing the existing suitability index variable (SIV) of habitat with the another generated suitability index variable.

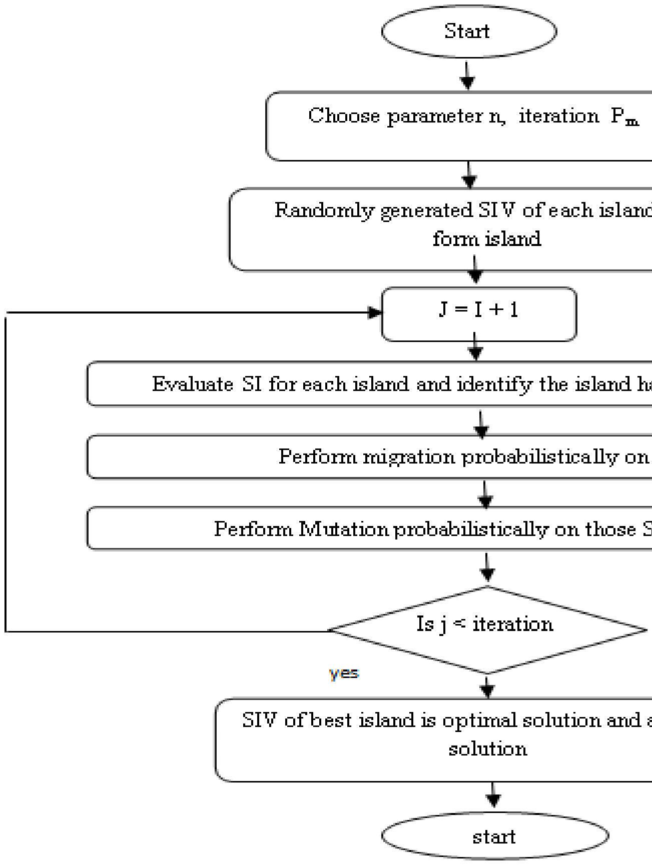

Figure 1: Flow Chart of BBO

RESULTS

An example is considered from [12] to demonstrate and validate optimization problem though turning process. In this section, a numerical study is performed to analyze the effects of decision variables. Evaluation and comparison is also done with the results given in the previous literature

Table1: Machining Data

Parameter /Constraints	Value	Parameter/ Constraint	Value	Parameter/ Constraints	Value	Parameter/ Constraints	Value
D	50 mm	L	300 mm	C_0	$6*10^{11}$	d_t	6mm
V_{Ru}	500 m/min	V_{rl}	50 m/min	V_{sU}	500 m/mn	V_{sL}	50 m/min
f_{rU}	0.9 mm/rev	f_{rl}	0.1 mm/rv	f_{sU}	0.9 mm/rv	f_{sL}	0.9 mm/rev
d_{rU}	3.0	d_{rl}	1.0	d_{sU}	3.0	d_{sL}	1.0
p	5	q	1.75	r	0.75	η	0.85
k_o	0.5 $/min	k_1	108	k_2	132	k_3	1.0
k_4	2.5	k_5	1.0	k_t	2.5 $/ege	θ	0.8
T_{min}	25 min	T_{max}	45 min	F_{max}	200 kgf	P_{max}	5 kw
μ	0.75	v	0.95	SR_U	10 µm	R	1.2 mm
λ	2	υ	-1	SC	140	Q_u	1000 ^{0}c
ζ	0.4	ϕ	0.2	δ	0.105	t_c	0.75 min/piece
h_1	$7*10^{-4}$	h_2	0.3	t_p	0.75 min/piece	t_e	1.5 mm/ege

Table 2: The Optimized Turning Parameters

Cutting Parameters			Cost	Iteration
ROUGHGING	SPEED	157.3932		
	FEED RATE	0.1142		
	DEPTH OF CUT	2.6482		
FINISING	SPEED	458.4504		
	FEED RATE	0.8641		
	DEPTH OF CUT	2.8079	1.2086	42

Table 3: Results of Optimization Using Different Algorithm

Algorithm	Cost
BBO	1.2086
ACO	1.8450
BFOA	1.4231
FIREFLY	2.5271
DE	2.8680
SA	2.2959
GA	1.761

Graph

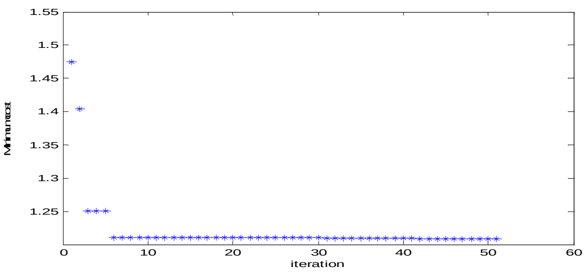

Figure 4: Graph of Minimum Cost Obtained Vs Iteration

Here in this problem, certain assumptions are taken as follows:

Population size = 100;

Probability of modification = 1;

Probability of mutation = 0.3;

Maximum mutate = 0.6;

Table2 Showing the optimal cutting parameters of the turning process used to get minimum production cost. From the table we can observe that bio-geography based optimization is giving minimum production cost e.g 1.2086 which is minimum than the algorithm proposed by various researchers. Ant colony algorithm (ACO) proposed by vijaykumar [9] achieves production cost equal to 1.8450 and also violates so many constraints. While simulated annealing proposed by Onwubolu [11] arrives at a production cost (UC) value of 1.761. In the above table we can observe that the proposed algorithm insures a minimum production cost with 45 % reduction in the production cost then in firefly algorithm. Whereas in other algorithm the production cost is higher as compare to the proposed algorithm. In GA algorithm, the production cost is less, but time taken during iteration is higher as compare to proposed algorithm. Hence, the proposed BBO algorithm is effective to solve such kind of optimization problem

CONCLUSIONS

In this paper, problem related to optimization of cutting parameters of turning process considering constraint is implemented and solved by using bio-geography based algorithm. The main aim of this project is to minimized total production cost. The cutting parameters as cutting speed, feed rate, depth of cut during roughing and finishing pass are the main process parameters whose optimal values effects the machining process. Many researchers solve this problem taking various algorithms, but total production cost (UC) came in this paper is comparatively low as compare to other algorithm implemented by other researchers. BBO provides better result with quality and feasibility. So we can say BBO is a reliable and efficient method for solving complex machining program

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