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TURNING PROCESS PARAMETER OPTIMIZATION USING SHUFFLED LEAF FROG ALGORITHM

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ABSTRACT

The iterative techniques are found to be more effective in solving hard combinatorial optimization problems that are less feasible by the real world experimentation due to the cost, time consumption, and safety risks involved in conducting the experiments. Among them, the bio-inspired algorithms because of their simplicity, adaptability, flexibility and less computation time are found to be very efficient in the selection of optimal cutting parameters for the specialized operations that are very complex in nature. In this article, it is intended to simplify the complex relations of tool geometry and machining parameters with tool life, roughness, and the quality of the machined products. This non-linear relation is carefully considered, analyzed and optimized using the Shuffled Leaf Frog Algorithm (SLFA). The worst frog in each memeplex is identified by a local exploration process and improved in every iteration by updating its position to make the algorithm more convergence. The shuffling of frogs between all memeplexes made this algorithm to explore a global search. The biological phenomenon of frogs can be successfully applied in the selection of optimized cutting parameters for the single pass turning process and is found to be excelling in solution quality as well as in computation time.

Keywords: Turning, Cutting Parameters, Shuffled Leaf Frog Algorithm, Memeplexes, And Local Exploration.

I INTRODUCTION

In this article, an attempt is made to develop a procedure using SLFA to optimize the machining parameters in one of the turning process. A mathematical model is built for the problem with an objective of minimizing the overall machining time. Here, the cutting speed and feed rate are taken as the decision variables. The constraints which represent the functional relationship between the decision variables and other design parameters satisfying certain physical phenomenon and certain resources limitations include, the minimum and maximum permissible cutting speed, the available spindle speed, the minimum and maximum permissible feed rate and the feed ranges available with the machine, the maximum cutting force the machine can withstand and maximum power, the maximum tool life desired and the surface finish required.

Some earlier attempts at multi constraint optimization of single pass turning operations have been reported in the late 1960s [1]. This lack of progress may be attributed to the complex nature of the problem which required a systematic approach to be applied to the machining operations. The solution for the optimized cutting

IJARSE
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conditions depends on the availability of quantitatively reliable technological machining performance equations relating to various cutting parameters such as cutting feed, speed, machining time and surface accuracy, etc.
Furthermore, a detailed knowledge of the machine tool capabilities is needed as well as an economically balanced performance measure is to be optimized together with the associated constraints. The complexity of the multi-constrained optimization for single pass turning operations has been demonstrated in a number of publications [2].

Here, it is proposed to develop an algorithm based on SLFA to achieve the minimization of the machining time by optimizing the cutting parameters. The obtained results are compared with the conventional results and other global optimal procedural results. The developed procedure was found to be producing best results that are nearer to the global optimal values. By involving the developed procedure for other machining operations, the total manufacturing time can be reduced considerably.

II EARLIER RESEARCH WORK

Generally, the selection of cutting parameters for metal cutting is left to the operator. The specialized skills and experiences acquired by the operator play a vital role in making such decisions. Unfortunately, it becomes very difficult for any skilled operator to select optimal values for all the processes. The basic parameters of metal cutting processes such as spindle speed, feed and depth of cut, etc are having direct impact on the quality of the components to be produced. When the tool life equation derived by Taylor [3] was introduced, many researchers carried out their work towards the optimization of process parameters related to metal cutting processes.

Armarego and Brown [4] investigated the unconstrained machine parameter optimization using differential calculus. Brewer and Rueda [5] carried out their work related to the simplified optimum analysis of non-ferrous metals. They employed a criterion to reduce the machining cost for cast iron and steel materials. Brewer [6] suggested the use of Lagrangial multipliers for the optimization of unit cost, with cutting power as the main constraint. Bhattacharya, et al. [7], used the Lagrange method to optimize the unit cost for turning taking the surface roughness and cutting power as constraints.

Walvekar and Lambert [8] used the geometric programming to select the metal cutting variables with an objective of minimizing the production cost by optimizing the cutting speed rate. Petropoulos [9] optimized the selection of cutting parameters such as cutting speed and feed rate using geometric programming. Wang, et al. [10], presented an optimization analysis, strategy and computer aided manufacturing software for the selection of economic cutting conditions in single pass turning operations using a deterministic approach. They aimed at the maximization of production rate with some practical constraints and had proved the economic benefits of using optimization procedures in the single pass turning process.

In solving the process optimization problems, the classical optimization methods are often encountered with great difficulties. Especially in some specific cases where we are dealing with the derivative problems, we are often locked with local optimal values. As the number of peaks and valleys (i.e. more in complexity of problems) of a domain increases, the possibility of getting global value is drastically reduced. This is because of some short comings remarked by traditional methods such as struck at local optima, need of existence of

IJARSE
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derivatives of objectives and constraint functions, requirement of mathematically well-defined objective and constraint functions, difficulty in handling mixed variables, involvement of more numerical steps and need for more computation time and moreover the real world is so complex [11].

Recently, a huge collection of optimization techniques have been suggested by many researchers of different fields starting from evolutionary algorithms, local search methods, trajectory based search algorithms and population based algorithms, etc. They are gaining greater significance because of their advantages in the computational time required, simplicity of formation and the adaptability to apply for any kind of simple to complex problems.

The bio-inspired algorithms especially, the swarm based optimization techniques were derived from Darwin's Evolutionary Theory of "Survival of fittest" [12]. Evolutionary algorithms are becoming very popular now because of their performances are independent of the nature of objective functions and constraints. Among them Shuffled Leaf Frog Algorithm (SLFA) has found to have a great potential in solving complex optimization problems that are non-linear, non-differentiable and having multi-model nature. [13] [14].

In this article, an evolutionary based swarm algorithm, SLFA is proposed to solve the process planning of single pass turning. The various parameters, terminologies and methodology of the proposed algorithm are discussed and the effectiveness of the SLFA is proved by considering a real world manufacturing problem.

III PROBLEM DESCRIPTION

In a research work by Taylor, a new tool life equation for CBN tools has been proposed and given in the equation Eqn.(1). This proposed tool life equation has two extreme values and is valid for the whole cutting speed range for a given feed rate and depth of cut.

$$:T = A \div \left(v^3 + \left(B \times v^2\right) + \left(C \times v\right)\right) \qquad \text{--- Eqn. (1)}$$

Where, "T" is tool life time and "*v*" is cutting speed. The coefficients A, B and C were calculated by fitting the Eqn. (1) to data which is obtained under different cutting conditions.

3.1. Problem Specifications

3.1.1. Material used:

Aluminum alloy; Diameter of job: 55 mm; Length of job: 60 mm (machining length); Tool life period: 300 min; Desired accuracy: 2 microns; Maximum power: 32 kW and Maximum force: 2000N.

3.2. Constraints

$$(140 =) v_{\min} \le v \le v_{\max} (= 200)$$
$$(0.02 =) f_{\min} \le f \le f_{\max} (= 0.1)$$
$$T_L \ge T_{L\_\min} (= 300)$$
$$F_c \le F_{c\_\max} (= 2000)$$
$$R_a \le R_{a\_\min} (= 2)$$
$$P_m \le P_{m\_\max} (= 32)$$

IJARSE
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where, v - permissible cutting speed; f - permissible feed rate; T_L - tool life time; F_c - actual cutting force; R_a - actual surface finish; P_m - actual power and min & max stands for the minimum and maximum values

3.3. Cutting parameters

Turning is the operation to remove excess material from the workpiece to produce a cylindrical surface. Speed, feed, depth of cut and machining time are some important cutting parameters for the turning process.

3.3.1. Selection of Tool material:

Cemented Carbide tools are produced by the cold compaction of the tungsten carbide powders in a binder such as cobalt followed by the liquid phase sintering. The major advantageous properties of these tools are their very high resistance to heat and wear. The working temperature may be 1273 K. However these are very brittle, have low resistance to shock and must be rigidly supported to avoid cracking. Cemented Carbide tools are most suitable for high cutting speed.

3.3.2. Selection of workpiece material:

Aluminium alloy is used for the workpiece material. It is a light weight material and gives good surface finishes. It has high heat transfer ratio and requires more cooling. Because of its ductility, resistance to corrosion, low melting point and less specific weight, it is used for the workpiece.

3.3.3. Cutting Speed

The speed of the milling cutter is its peripheral linear speed resulting from rotation. It can be defined as the speed at which the cutting edge passes over the material. It is often referred to as surface speed and is expressed in meters per minute.

$: v = (3.14 \times \phi \times N) \div 1000$ --- Eqn. (2)

Where, ϕ is the diameter of the component and N is the spindle speed in rpm

3.3.4. Feed rate

It is the distance the tool advances into or along the workpiece each time the tool point passes a certain position in its travel over the surface of the component under machining.

3.5.5. Tool Life

Tool life directly depends on the cutting speed and feed rate.

$: T_L = (2.4554 \times 10^9) \div (v^{(1 \div 0.245)} \times f^{(1 \div 0.411)})$ --- Eqn. (3)

3.5.6. Cutting force:

$: F_c = 1456.26 \times D_e^{1.06} \times f^{0.67}$ --- Eqn. (4)

Where, D_e is the depth of cut

3.5.7. Surface finish:

$: R_a = f^2 \times 0.256 \times 8 \times r_n$ --- Eqn. (5)

Where, r_n is the tool nose radius

IJARSE
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3.5.8 Spindle Speed:

: $S = v_s \times 1000 \div (\pi \times d)$ --- Eqn. (6)

3.5.9 Power:

: $P_m = 0.0242 \times D_e^{1.06} \times f^{0.67} \times v$ --- Eqn. (7)

IV SHUFFLED LEAF FROG ALGORITHM

The researchers carried out several studies about mimicking the biological phenomena in the field of operations research. Lot of evolutionary algorithms were framed and found to be very excellent in solving the optimization problems belonging to several domains especially in the manufacturing field. The wonderful characteristics of swarms were observed and the process of correlating them with the optimization problems is growing in a rapid manner. SFLA is a bio-inspired algorithm that mimics the metaphor of natural biological evolution of frogs' population in searching of their food for survival [15] [16]. The SLFA is a convergence based local search algorithm that is always stochastic in nature.

4.1. SLFA Procedure

The various parameters, stages and criteria involved in this local search meta-heuristic procedure are explained in this chapter.

Step 1. Initialization of Population

This SLFA procedure starts with an initial population similar to most of the bio-inspired algorithms. Usually the initial population of frogs (F_ini_pop) is generated randomly. These randomly generated frogs represents the decision variables of the objective function.

For a K-dimensional problem i.e., problems with "k" number of variables, a frog "i" is represented as,

Fi = (fi1, fi2, fi3, ……….., fik) --- Eqn. (8)

Step 2. Evaluation & Ranking of Population

The objective function of each frog in the initial population is evaluated. Then the frogs are ranked according to their fitness values and are sorted in a descending order for further process.

Step 3. Distribution of Population

Then the total population (m * n) is divided into "m" number of sub groups called as memeplexes with "n" number of frogs in each memeplex. During this process, the first frog goes to the first memeplex, the second frog goes to the second memeplex, … , frog "m" goes to mth memeplex, and the frog "m+1" goes to the first memeplex, and so on.

Step 4. Assignment of Population

Within each memeplex, the frogs with best fitness value is assigned as F_mem_best and the frogs with worst fitness value is assigned as F_mem_worst. Also the frog with best fitness value among all frogs in all memeplexes is assigned as F_pop_best.

IJARSE
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Step 5. Local Exploration

Then an evolution process is applied to improve the location of needy frog i.e. frog with worst value in each iteration. The new location of the frog with worst fitness, F_mem_worst is calculated and improved as described below.

Change in location of frog (F_mem_worst) is,

: ΔX = rand (#) * [X(F_mem_best) – X(F_mem_worst)] + rand (#) * [X(F_pop_best) – X(F_mem_worst)] --- Eqn. (9)

New location of the frog (F_mem_worst) is,

: X(F_mem_new) = X(F_mem_worst) + ΔXi; $\Delta Xmax \leq \Delta Xi \leq \Delta Xmax$ --- Eqn. (10)

where rand (#) is random number between 0 to 1 and $\Delta Xmax$ is the maximum permitted change value in the frog's location in an iteration.

Step 6. Appraisal Function

The fitness value of the frog (F_mem_new) is evaluated and compared with its original fitness value i.e. fitness value of frog (F_mem_worst). If there is an improvement then frog (F_mem_worst)'s location is replaced with location of frog (F_mem_new).

Otherwise, the location of the frog (F_pop_best) is modified as per above equations eqn. (New1) and eqn. (New2) i.e., we are replacing the frog (F_mem_worst) by frog (F_pop_best). Then the fitness value of frog (F_pop_best) is calculated as frog (F_pop_new).

Step 7. Update Function

Now the fitness value of frog (F_pop_new) is compared with fitness value of frog (F_pop_best) for any improvement. If there is an improvement, then, then frog (F_mem_worst)'s location is replaced with location of frog (F_pop_new).

Otherwise, a new virtual frog (F_virtual) is randomly generated to replace the worst frog (F_mem_worst) with another frog having any arbitrary fitness.

This evaluation process continues for a predefined number of iteration within each memeplex.

Step 8. Shuffling Operation

Here all the frogs (p) in all the memeplexes (n * m) are shuffled for global information exchange.

Step 9. Termination criteria

The local exploration and global shuffling processes are continued until a predefined convergence criteria has been met.

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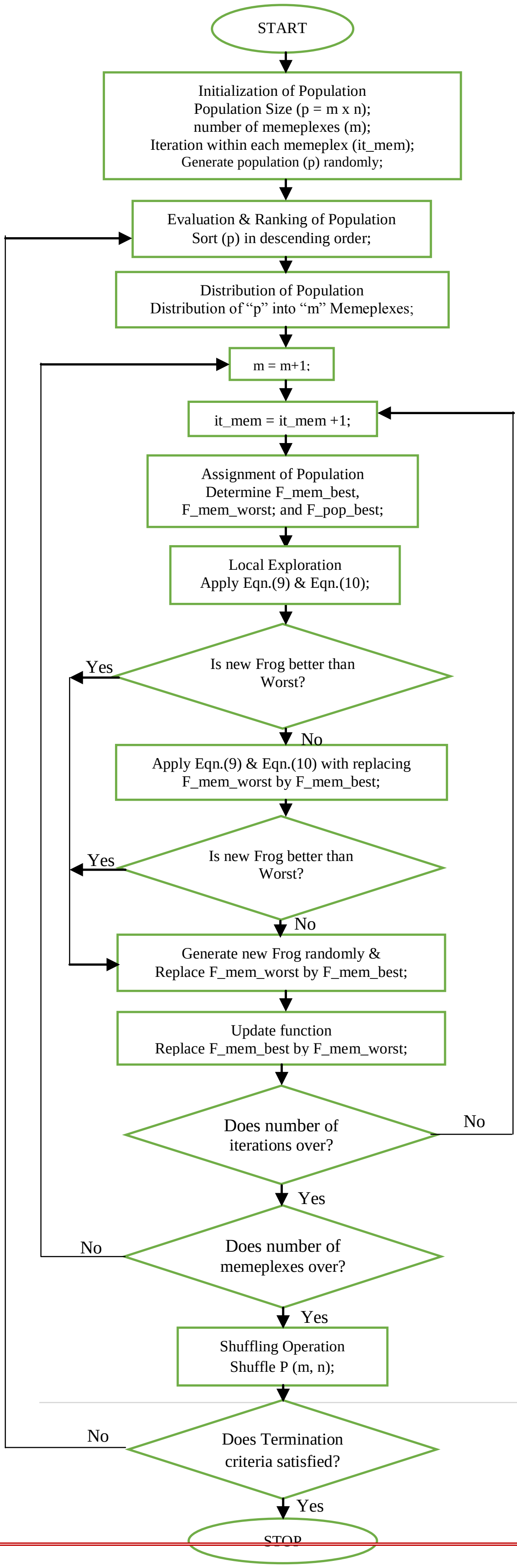
4.2. SLFA Flowchart



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V RESULTS AND DISCUSSIONS

Here carbide coated cutting tool was used to remove the excess material from the aluminium workpiece. The cutting speed and feed rate of the turning process were taken as decision variables and the constraints were formed as discussed above. For the designed SLFA Method, a procedure is developed using software to conduct experiments. A list of worst solutions is used to denote frogs to be updated in the particular iteration and are allowed to evolve as elite solutions by global shuffling among the memeplexes. For the experimental problem, the optimal values obtained by SLFA are given in the Table II. The comparison between different techniques are given in the Table III. It reveals that the desired optimization procedure will produce economical results in terms of reduced manufacturing time for the single pass turning process.

TABLE 1

SAMPLE RESULTS OF SLFA BASED PROCEDURE

Trial No.	Feed in mm/rev	Speed in m/min	Machining Time in sec
01	0.098	196.30	1.98
02	0.100	191.20	1.96
03	0.100	192.20	1.96
04	0.100	192.40	1.96
05	0.100	192.40	1.96
06	0.096	199.40	1.98
07	0.100	190.90	1.96
08	0.100	190.90	1.96
09	0.098	196.30	1.98
10	0.098	196.30	1.99

TABLE 2

COMPARISON BETWEEN DIFFERENT TECHNIQUES

Sl. No.	Methodology	Feed in mm/rev	Speed in m/min	Machining Time in sec
01	Conventional Techniques	0.100	180.00	2.20
02	Particle Swarm	0.098	196.30	1.98

IJARSE
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	Optimization Procedure			
03	Bee Colony Optimization algorithm	0.096	199.40	1.98
04	Shuffled Leaf Frog Algorithm	0.096	196.40	1.96

VI CONCLUSION

In this paper a new methodology developed using SLFA is employed for the optimization of cutting parameters such as speed, feed and machining time for turning process. The machining time results obtained by this mechanism are compared with conventional methodologies and were found to be superior. Although the main focus of this research is to devise a mechanism to produce optimum parameters for turning process, it has been found that there is also ample scope for further research relating to choice of other parameters of SLFA algorithm. This theoretical research work leads to a conclusion that the developed procedure can suitably be modified to any kind of machining process and by applying this developed algorithm the total machining time can be reduced to a significant level.

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