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Genetic algorithm-based optimization of cutting parameters in turning processes

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Abstract

An optimization paradigm based on genetic algorithms (GA) for the determination of the cutting parameters in machining operations is proposed. In metal cutting processes, cutting conditions have an influence on reducing the production cost and time and deciding the quality of a final product. In order to find optimal cutting parameters during a turning process, the genetic algorithm has been used as an optimal solution finder. Process optimization has to yield minimum production time, while considering technological and material constrains.

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Keywords: Metal cutting; Cutting parameters optimization; Genetic algorithm

1. Introduction

In today's production systems, many industries have made an effort to introduce flexibility as their strategy to adapt to the ever-changing competitive market requirements. To ensure the quality of machining products, and to reduce the machining costs and increase the machining effectiveness, it is very important to select the machining parameters when the process parameters are selected in CNC machining. The traditional methods for solving this class of optimization problem include dynamic programming, random searches, and gradient methods whereas modern heuristic methods include, cognitive paradigms as artificial neural networks, simulated annealing [1] and Lagrangian relaxation approaches [2]. Some of these methods are successful in detecting the optimal solution, but they are usually slow in convergence and require much computing time.

Genetic algorithms (GA) approach, based on the principles of natural biological evolution will be used to tackle this kind of problem. Compared to traditional optimization paradigms, a GA is robust, global and may be applied generally without recourse to domain-specific heuristics. It can be used not only for general optimization problems, but also in indifferent optimization problems and unconventional optimization problems. So GAs are widely used for machine learning, function optimizing and system modeling [3 - 7]. Although GA is an effective optimization algorithm, it usually takes a long time to optimize machining parameters because of its slow convergence speed.

The main objective of this paper is to determine the optimal machining parameters during a turning process that minimize the production time without violating any imposed cutting constraints.

2. Genetic Algorithm

A GA is a paradigm that tries to mimic the genetic evolution of a species. Specifically, GA simulates the biological processes that allow the consecutive generations in a population to adapt to their environment. The adaptation process is mainly applied through genetic inheritance from parents to children and through survival of the fittest. Therefore, GA is a population-based search methodology [8, 9].

The GA starts with a randomly generated population of individuals, each one made by strings of the design variables, representing a set of points spanning the

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search space. Each individual is suitably coded into a chromosome made by a string of genes: each gene encodes one of the design parameters, by means of a string of bits, a real number or other alphabets.

In order to evaluates and rank chromosomes in a population, a fitness function based on the objective function should be defined. New individuals are then generated by using some genetic operators, the classical ones being the crossover, the selection and the mutation.

The selection operator cares with selecting an intermediate population from the current one in order to be used by the other operators, crossover and mutation. In this selection process, chromosomes with higher fitness function values have a greater chance to be chosen than those with lower fitness function values. Pairs of parents in the intermediate population of the current generation are probabilistically chosen to be mated in order to reproduce new individuals. In order to increase the variability structure, the mutation operator is applied to alter one or more genes of a probabilistically chosen chromosome. Finally, another type of selection mechanism is applied to copy the survival members from the current generation to the next one.

The crossover operator aims to interchange the information and genes between chromosomes. Therefore, crossover operator combines two or more parents to reproduce new children, then, one of these children may hopefully collect all good features that exist in his parents. Crossover operator is not typically applied for all parents but it is applied with probability which is normally set equal to 0.6.

The mutation operator alters one or more gene in a chromosome. Mutation operator aims to achieve some stochastic variability of GA in order to get a quicker convergence. The probability of applying the mutation operator is usually set to be small, normally 0.01.

The fitness function is a designed function that measures the goodness of a solution. It should be designed in the way that better solutions will have a higher fitness function value than worse solutions. The fitness function plays a major role in the selection process.

3. GA based optimization of turning parameters

3.1. Production model design

Intelligent manufacturing achieves substantial savings in terms of money and time if it integrates an efficient automated process-planning module with other automated systems such as production, transportation, assembly, etc.

Process planning involves determination of appropriate machines, tools for machining parts, cutting fluid to reduce the average temperature within the cutting zone and machining parameters under certain cutting conditions for each operation of a given machined part.

The machining economics problem consists in determining the process parameter, usually cutting speed, feed rate and depth of cut, in order to optimize an objective function.

A number of objective functions by which to measure the optimality of machining conditions include minimum unit production cost, maximum production rate, maximum profit rate.

Several cutting constraints that should be considered in machining economics include: tool-life, cutting force, power, stable cutting region, chip-tool interface temperature, surface finish, and roughing and finishing parameter relations.

The main objective of the present paper is to determine the optimal machining parameters that minimize the production time without violating any imposed cutting constraints. The entire development of planning of the machine processes is based on the optimization of the economic criteria by taking into account the technical and organizational limitations.

Several practical cutting constraints that were considered in the optimization of the production time in machining economics include: tool-life constraint, cutting force constraint, power, stable cutting region constraint, chip-tool interface temperature constraint, surface finish constraint, roughing and finishing parameter relations, and the number of passes.

Usually, the production time is measured as the time necessary for the fabrication of a product, T_p:

$$T_p = T_s + V(1 + T_c/T)/MRR + T_i \quad (1)$$

where T_s, T_c, T_i, V and MRR are the tool set-up time, the tool change time, the time during which the tool does not cut, the volume of the removed material and the material removal rate. In some operations, the T_s; T_c, T_i and V are constants so that T_p is the function of MRR and T.

The material removal rate MRR is expressed by analytical starting point as the product of the cutting speed, v, feed rate, f, and depth of cut, a:

$$MRR = 1000*v*f*a \quad (2)$$

The tool life, T, is measured as the average time between the tool changes or tool sharpenings. The relation between the tool life and the parameters is expressed with the Taylor's formula:

$$T = K_T/v^{\alpha}*f^{\alpha 1}*a^{\alpha 3} \quad (3)$$

where K_T, α_1, α_2 and α_3, which are always positive constant parameters, are determined statistically.