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Overview of NSGA-II for Optimizing Machining Process Parameters

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Abstract

This paper presents an overview on NSGA-II optimization techniques of machining process parameters. There are many multi objective optimization (MoGA) techniques involved in machining process parameters optimization including multi-objective genetic algorithm (MOGA), strength Pareto evolutionary algorithm (SPEA), micro genetic algorithm (Micro-GA), Pareto-archived evolution strategy (PAES), etc. This paper reviews the application of non dominated sorting genetic algorithm II (NSGA-II), classified as one of MoGA techniques, for optimizing process parameters in various machining operations. NSGA-II is a well known, fast sorting and elite multi objective genetic algorithm. Process parameters such as cutting speed, feed rate, rotational speed etc. are the considerable conditions in order to optimize the machining operations in minimizing or maximizing the machining performances. Unlike the single objective optimization technique, NSGA-II simultaneously optimizes each objective without being dominated by any other solution.

*Keywords:*Machining; Optimization Technique, NSGA-II

1. Introduction

Machining operation is a very important process in the manufacturing industry and generally described as a mechanical process of materials cutting by using specified tools. Basically there are two types of machining operations which are traditional and modern machining respectively. The most common traditional machining operations are turning, drilling, milling and grinding. Advanced machining operations such as abrasive water jet machining (AWJ), electrical discharge machining

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(EDM), electrochemical machining (ECM) etc. are some examples of the modern machining operations. Maximizing the production rate, minimizing operational cost and maximizing the profit rate are the three conflicting machining operation objectives that need an intensive consideration in the real machining application. There are many soft computing optimization techniques such as ant colony optimization (ACO), simulated annealing (SA), particle swarm optimization (PSO), genetic algorithm (GA) etc. that are classified as single objective optimization, which have been applied in the real world application.

MoGA has become a new trend in recent research in optimizing machining process parameters. Different from MoGA, objectives always conflict among each other when using single objective GA optimization technique and can causes unbalance results output. By using the MoGA optimization technique, problems with more than one objective functions are concurrently optimized. Several Pareto optimal points can simultaneously obtain with an even distribution solutions from the Pareto optimal sets that exist which can reduce the production time and cost. There are many new multi objective optimization techniques which are enhancement from single objective optimization GA [1]. They include MOGA, NSGA-II, SPEA, Micro-GA, PAES etc. [2,3,4,5]. Among of all MoGA techniques, literature shows that NSGA-II has been most widely applied for optimizing machining process parameter. The interest of this study is to review the application of the NSGA-II in optimizing machining process parameters.

2 Overview of NSGA-II

NSGA-II is one of the most popular multi objective optimization algorithms with three special characteristics, fast non-dominated sorting approach, fast crowded distance estimation procedure and simple crowded comparison operator [2]. Deb et al. [7] simulated several test problems from previous study using NSGA-II optimization technique, and it is claimed that this technique outperformed PAES and SPEA in terms of finding a diverse set of solutions [3,5]. Generally, NSGA-II can be roughly detailed as following steps.

Step 1: Population initialization

Initialize the population based on the problem range and constraint.

Step 2: Non dominated sort

Sorting process based on non domination criteria of the population that has been initialized.

Step 3: Crowding distance

Once the sorting is complete, the crowding distance value is assign front wise. The individuals in population are selected based on rank and crowding distance.

Step 4: Selection

The selection of individuals is carried out using a binary tournament selection with crowded-comparison operator$(\prec_n)$.

Step 5: Genetic Operators

Real coded GA using simulated binary crossover and polynomial mutation.

Step 6: Recombination and selection

Offspring population and current generation population are combined and the individuals of the next generation are set by selection. The new generation is filled by each front subsequently until the population size exceeds the current population size.

3 NSGA-II in Machining Optimization

This section briefly summarized NSGA-II optimization technique application in machining operations. Fig. 1 shows the general approach of machining process parameters optimization procedure using NSGA-II. Basically, a machining model is generated based on previous experimental data to correlate the input and output data. Regression analysis, artificial neural network (ANN) and fuzzy theory are commonly used for generating relations between machining performances and machining process parameters. In order to formulate an optimization problem of NSGA-II, the process parameters are considered as decision variables for minimizing or maximizing the machining performances which is the fitness values.

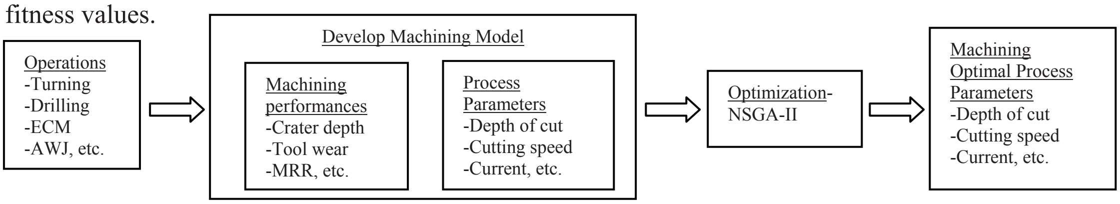

Fig. 1. NSGA-II approach for machining process parameters optimization

3.1 NSGA-II for traditional Machining Operations

Traditional machining can be described as machining operations that use single or multi-point tools to remove material in the form of chips. This sub section reviewed the previous researches on using NSGA-II as optimization technique for traditional machining operations. Mitra & Gopinath [12] explored in adapting NSGA-II for optimizing the industrial grinding operation of a lead-zinc ore beneficiation. Two objective functions considered in this study are maximizing grinding product throughput and maximizing percentage passing of midsize. Three process parameters are optimized, the solid ore flowrate, primary water flowrate and secondary water flowrate. In this study, the authors compared the spread of Pareto front found from NSGA-II optimization technique and SOOP (single objective optimization problem) formulation for MOOP (Multi-objective optimization problem) using weighted average approach or constraint based approach. It can be concluded that the quality of Pareto front found out by NSGA-II is better than the other technique. Kodali et al. [3] used NSGA-II to solve problem involves two objectives, four constraints and ten decision variables of the grinding machining operation. The Pareto-optimal front obtained is compared with earlier reported results of quadratic programming (QP), GA, PSO, scatter search (SS), ACO, differential evolution (DE), and it shows that NGSA-II outperformed others. R. Datta et al. [4] presented a study in optimizing the cutting speed, feed and depth of cut for a turning operation. The considered objectives are minimizing production time, minimizing production cost and minimizing surface roughness. Pareto front is considered as two dimensional where one objective is redundant. NSGA-II is used to get a Pareto-optimal front to solve the three-objective optimization problems by considering the function as a two objective problem neglecting one objective in each run. A local search strategy is recommended from each obtained Pareto points in order to get a better solution in this study. Jianling [5] proposed an improved NSGA-II in order to deal with multiple constraints in milling operation. Minimal machining time and minimal elapsed tool life were considered. By extending the non-dominance concept to constraint space of NSGA-II, the optimization process become more approximate to application, more economical and effective in searching the Pareto front.

Latha et al. [6] presented investigation focuses on the three objective multiple performance optimization of drilling parameters in drilling of composite drilling process. Spindle speed, feed speed and drill diameter on maximizing material removal rate and minimizing thrust force and surface roughness are the process parameters and machining performances that are considered in this study. Experiment were done using computer numeric control (CNC) drilling machine with carbide drill bit. Second order regressions are developed and NSGA-II is used to optimize the drilling conditions. A non-dominated solution set has been obtained and this shows that the algorithm is suited for getting Pareto frontier in optimization of drilling parameters. Mitra [7] considered two sources of uncertainties, (i) parameters that are used inside a model representing the process under consideration and subjected to experimental and regression errors and (ii) parameters that express operators choice for assigning bounds in the constraints and operators prefer them to be expressed around some value rather than certain crisp value. A combination of fuzzy and chance constrained programming approach is used to overcome this problem. Optimization model of Mitra et al. [8] and NSGA-II optimization approach is used in this study. The study improved as compared to the deterministic optimization problem. Palanikumar et al. [9] investigated multiple performance optimization on machining characteristics of glass fibre reinforced plastic (GFRP) composites. The considered cutting parameters were cutting speed, feed and depth of cut. Second order polynomial equations were developed to describe the dependent and independent variables. NSGA-II was used to optimize the cutting conditions where this method help in increasing production rates considerably by reducing machining time. Yang & Natarajan [10] solved multi-objective optimization problem in turning by using multi-objective differential evolution (MODE) algorithm and NSGA-II. The considered machining parameters are cutting speed, feed rate, and depth of cut. Regression models were developed for minimizing tool wear and maximizing material removal rate (MRR). The non-dominated solution set obtained from MODE was compared with NSGA-II, and it was found that NSGA-II outperformed MODE in the context of number of solutions and ratio of non dominated individuals.

3.2 NSGA-II for Modern Machining Operations

Modern machining can be explained as the use of chemical, thermal, or electrical processes to machine a workpiece and remove material. Mandal et al. [11] optimized the EDM process using soft computing techniques. ANN with back propagation algorithm is used to model the process. NSGA-II is used to optimize the process. The author concluded that from the experiments and testing results, this model is suitable for predicting the process parameters. Kanagarajan et al. [12] evaluated the effectiveness of the EDM process with tungsten carbide and cobalt composites. Process parameters of EDM such as pulse current, pulse on time, electrode rotation and flushing pressure on material removal rate and surface roughness are investigated. Second order polynomial equations were used as the machining model and NSGA-II has been used to optimize the processing conditions. EDM process parameters have been optimized by using NSGA-II and non dominated solutions obtained from this study. Senthilkumar et al. [13] improved cutting parameters of ECM using NSGA-II to maximize MRR and minimize surface roughness. Electrolyte concentration, electrolyte flowrate, applied voltage, and tool feed rate are the considered cutting parameters and second-order polynomial equations were developed for the different rmachining performances. As a result, a non-dominated solution set has been obtained.

Joshi et al. [14] reported modeling process using finite element method (FEM) integrated with ANN and GA to improve in predicting the shape of crater, MRR and tool wear rate (TWR). ANN based model is proposed to relate the process parameters (current, discharge voltage, duty cycle and discharge duration) and the machining performances (crater size, MRR and TWR). The ANN model was trained, tested and tuned by using the data generated from FEM model. NSGA-II was used to select optimal process parameter of EDM. Verification was done by comparing experimental results with results obtained from proposed approach. Thus, the proposed approach gives the expected optimum performance of the EDM process. Kondayya et al. [15] presented an application of an integrated evolutionary approach. Genetic programming (GP) is proposed to model highly non-linear and complex processes. Machining performance of WEDM, metal removal rate and surface roughness, are modelled based on experimental data using GP in terms of input variables. Machining performances is formulated as a multi-objective optimization problem and solved using NSGA-II. In this way, a new evolutionary approach for optimization has been proposed and the Pareto optimal solutions are obtained.

4 Conclusion

An overview of NSGA-II optimization technique and review of application of NSGA-II in machining operations has been presented. As a conclusion, NSGA-II as part of MoGA is a popular and reliable technique that can be used in optimizing the process parameters of multiple machining performances. It can be observed that; (i) ANN, GP, fuzzy, regression analysis are some of the methods used in modeling the machining performance prediction, (ii) NSGA-II is a multi objective optimization tool that can meet the requirements of the machining process in finding set of solutions based on combination of suitable variables.

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