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An Overview of Optimization Techniques for CNC Milling Machine

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***Abstract*— This paper discuss of the literature review of optimization of milling machining process parameters for composite materials. Machining process has characteristics that describe their performance relative to efficient use of machine tools by setting optimum cutting parameters. The traditional optimization techniques are not suitable because milling machining operation is highly constrained in nature. For this reason we propose a modified optimization methodology based on hitherto research study for milling machining parameters.**

***Index Terms*— Milling, Cutting parameters, Taguchi method, Response surface method, Genetic algorithm, optimization.**

I. Introduction

Increasing demand of quality of the machined parts are the main challenges in the global competition manufacturing market. Quality of a process is measured in terms of characteristics. Surface finish is an important quality that is a characteristic that could influence the performance of machining part and production cost. Quality and productivity are two important but conflicting criteria in any machining operations. In order to ensure high productivity, extent of quality is to be compromised. An improvement in quality results in increasing machining time thereby, reducing productivity [1]. Machining conditions are set on CNC machine as per standard handbook, which are far from reality. Many efforts have been done to optimize machining parameters for lathe operations, however milling operation on composite materials, has gained little attention. Owing to the significant role that milling operations play in today's manufacturing world, there is a vital need to optimize milling machining for this operation, particularly when NC machines are employed [2]. Due to these reasons optimization of machining process parameters is the key component in manufacturing environment.

II. Milling Process

Milling is a multi-purpose and useful machining operation. End milling process is one of the most fundamental and commonly encountered material removal operations in manufacturing industries including the automobile and aerospace sector where quality is an important factor in the production of slots, pockets and moulds/dies [3]. The surface roughness plays a great part in fatigue strength and corrosion resistance, surface friction, light reflection, ability of holding a lubricant, electrical and thermal contact resistance, appearance, cost, etc [4]. For the efficient use of the machine tool it is important to find the optimum cutting parameters before a part is put into production. The independent variables for optimal cutting parameters are tool diameter and tool length, Number of passes, Depth of cut (radial and axial), Spindle speed or cutting speed and Feed (per tooth, per revolution or per unit time), etc. For a single pass end milling operation optimization, the radial depth of and axial depth of cut are shown in Figure-1 [2].

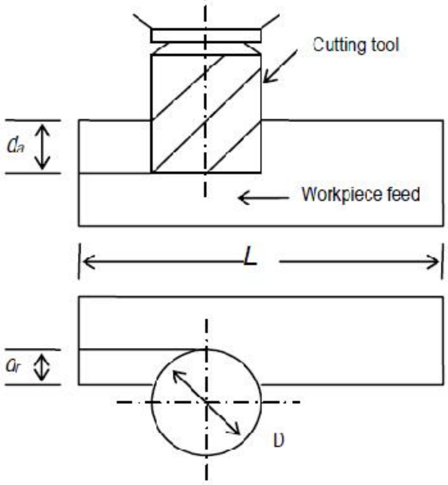

Figure-1

Figure-2 shows the fishbone diagram with the parameters that affect surface roughness.

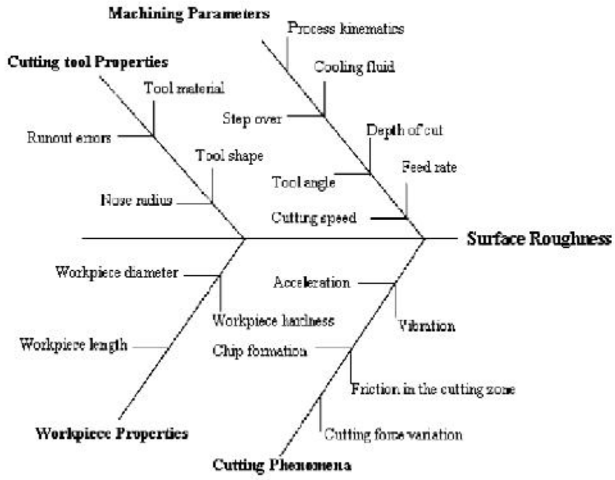

Figure-2

III. Cutting Constraints

Cutting process has many constraints that must be satisfied for a meaningful optimization of machining process. In milling machining process constraints like Surface finish

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requirements, Speed on the machine tool, available feed rates, etc are considered.

A multi objective parameter optimization problem can be formulated as follow:

Minimize or *Maximize* $[f_1(x), f_2(x),..., f_n(x)]$

subject to

$$g_j(x) \geq 0 \qquad j = 1,2,...,m$$
$$h_j(x) = 0 \qquad j = 1,2,...,p< n$$

where x is a n-dimensional design variable vector, $f_i(x)$ is the objective function, $g_j(x)$ and $h_j(x)$ are inequality and equality constraints.

IV. COMPOSITE MATERIAL

In recent years, the utilization of composites materials in many engineering fields has increased tremendously. The biggest advantage of modern composite materials is that they are light as well as strong. By choosing an appropriate combination of matrix and reinforcement material, a new material can be made that exactly meets the requirements of a particular application. The applications of metal matrix composites (MMCs) are being increasing day to day in both the aerospace and automobile industries, because of their improved properties compared to alloy metals. Composites materials has attributed to their superior specific strength and specific stiffness, high temperature capability, lower coefficient of thermal expansion, better wear resistance, improved dimensional stability, and amenability to conventional metal forming techniques [20].

V. EXPERIMENT METHODOLOGY

The purpose of process development is to improve the performance characteristics of process relative to customer needs and expectations [5]. Focused areas experimental methodology implemented in vast areas of milling machining process. Design of experiment implemented to model the end milling process that are using solid carbide flat end mill as the cutting tool and stainless steels s.s-304 as material due to predict the resulting of Tool life [7]. Individual response correlations have been eliminated first by means of Principal Component Analysis (PCA). Correlated responses have been transformed into uncorrelated or independent quality indices called principal components. The principal component, imposing highest accountability proportion, has been treated as single objective function for optimization (multi-response performance index) [1]. Taguchi dynamic characteristic theory coupled with ideal function models under a two-phase optimization strategy and develops optimized machining parameters in the high-speed milling process with the characteristics of high machining efficiency and geometrical accuracy, and wide applications [8]. The predicted optimal setting ensured minimization of surface roughness and maximization of MRR (Material Removal Rate). This is done by response surface methodology (R.S.M), which is a part of DOE is used to determine and present the cause and effect of the relationship between true mean response and input control variables influencing the response as a two or three dimensional surface. R.S.M has been used for designing a three factor with three level central composite factors design in order to construct statistical models capable of accurate prediction of responses [9]. The taguchi design method implemented to optimize the surface roughness quality in a computer numerical control end mills Taguchi's parameter design is an important tool for robust design, which offers a simple and systematic approach to optimize a design for performance, quality and cost [10]. The effect of machining parameters on surface roughness is evaluated and the optimum cutting condition for minimizing the surface roughness is determined [11]. Taguchi method has shown that the cutting speed has significant role to play in producing lower surface roughness about 57.47% followed by feed rate about 16.27%. The depth of cut has lesser role on surface roughness from the tests [12]. Developed optimization procedures based on the genetic algorithm, tabu search, ant colony algorithm and particle swarm optimization Algorithm for the optimization of machining parameters for milling operation. This paper describes development and utilization of an optimization system, which determines optimum machining parameters for milling operations [13].

The review of literature on roughness modeling of milled surfaces reveals optimization tools and techniques are classified into two parts:

(A) Conventional Techniques [Optimal Solution]

Further classified into two parts:

(i) Design of Experiment

Further classified into three parts:

(a) Taguchi Method Based
(b) Factorial Design Based
(c) Response Surface design Methodology (RSM) Based

(ii) Mathematical iterative Search

Further classified into three parts:

(a) Dynamic Programming based
(b) Non linear programming based
(c) Linear programming based

(B) Non-Conventional Techniques [Near Optimal Solution(s)]

(i) Meta Heuristic Search

Further classified into three parts:

(a) Genetic Algorithm
(b) Simulated Annealing Algorithm
(c) Tabu Search

In this paper, propose some experiment methodologies on the generalized optimization techniques is illustrated.

(A) Design of Experiment (DOE):

Design of experiments (DOE) is a statistical technique that is used to determine the relationship between the different factors of input variables that affects a process and the output or response of that process. Design of Experiment involves designing a set of experiments, in which all relevant factors are varied systematically. When the results of these experiments are analyzed, they help to identify optimal conditions, the factors that most influence the results, and those that do not, as well as details such as the existence of interactions and synergies between factors. When applied to product or process design, the technique helps to seek out the best design among the alternatives [6].

(a) Taguchi Method

Dr. Genichi Taguchi, a Japanese management consultant developed an efficient methodology to optimize quality characteristic and is widely being applied now-a-days for continuous improvement and off-line quality control of any manufacturing/production process or product.

The major steps to complete an effective designed experiment are listed as [5,6]:

Step-1: Define the problem(s) or area(s) of concern.
Step-2: Define the process objective, or more specifically, a target value for a performance measure of the process.
Step-3: Define the quality characteristic(s) and measurement system (s).
Step-4: Determine the design parameters /factors affecting the selected quality characteristics.
Step-5: Select control and noise factors.
Step-6: Select levels for the factors.
Step-7: Create orthogonal arrays for the parameter design indicating the number of and conditions for each experiment.
Step-8: Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.
Step-9: Complete data analysis and interpret results for determining the effect of the different parameters on the performance measure.
Step-10: Conduct confirmation experiment.

(b) Response surface method

Response surface method (RSM) adopts both mathematical and statistical techniques which are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize the response [17]. In most of the RSM problems, the form of the relationship between the response and the independent variables is unknown. Thus the first step in RSM is to find a suitable approximation for the true functional relationship between response of interest 'y' and a set of controllable variables {x_1, x_2, ...xn}. Usually when the response function is not known or non-linear, a second-order model is utilized [17] in the form:

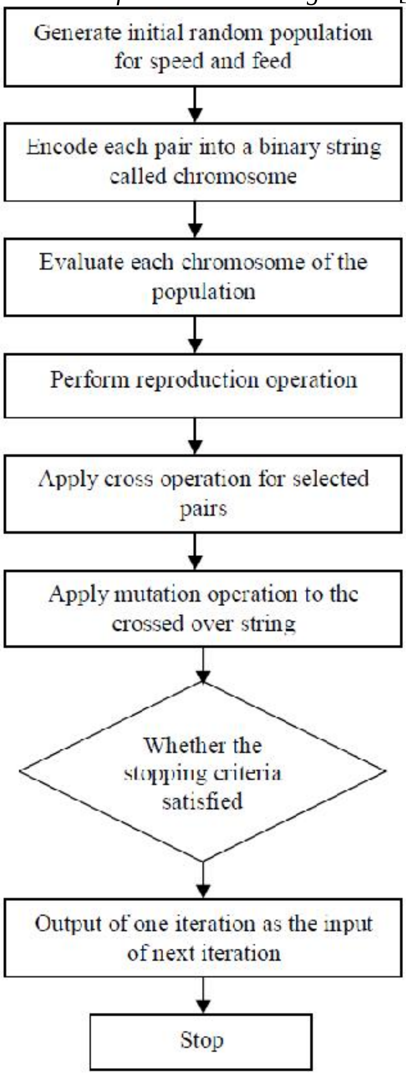
$$y = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n} b_{ii} x_i^2 + \sum \sum_{i<j} b_{ij} x_i x_j + \varepsilon$$

where, ε represents the noise or error observed in the response y such that the expected response is (y -ε) and b's are the regression coefficients to be estimated. The least square technique is being used to fit a model equation containing the input variables by minimizing the residual error measured by the sum of square deviations between the actual and estimated responses. The calculated coefficients or the model equations, however, need to be tested for statistical significance.

(c) Genetic Algorithm:

Genetic algorithm (GA) is a popular evolutionary algorithm, which has been applied in optimization of metal cutting operations, especially in the optimization of machining operations with an objective function. The problem of the optimal machining condition selection has been analyzed by many researches. Some of the authors analyzed the optimum cutting speed that satisfies the basic manufacturing criteria's.

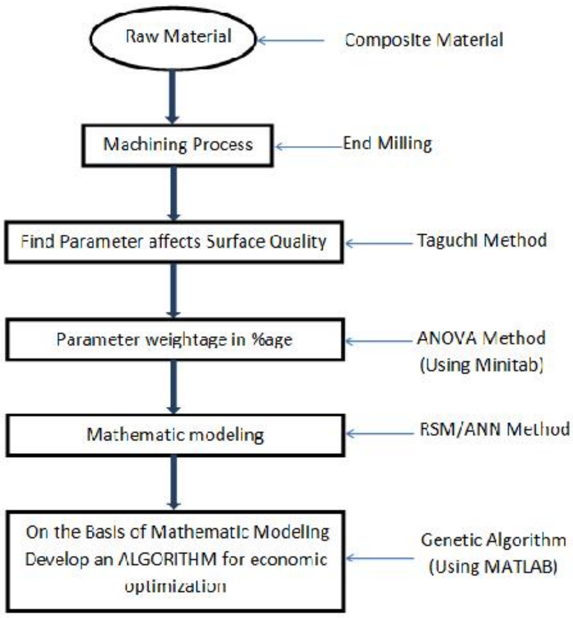
Flowchart for the Genetic Algorithm [18]*:*



VI. Results and Discussion

The literature review shows that various optimization techniques like Taguchi technique, Response surface method, Genetic Algorithm etc. have been successfully applied in the past for optimizing the various cutting process parameters of milling machining. Taguchi technique, response surface methodology and genetic algorithm are the efficient optimization techniques that are being applied successfully in industrial applications for optimal selection of process parameters with economic production cost in the area of machining for making the process insensitive to any uncontrollable factors such as environmental variables. On the basis of literature we made a algorithm for milling machining parameter optimization with economic consideration.

Flowchart for proposed optimization algorithm



Above optimization algorithm of modeling and determination of optimal or near-optimal cutting process parameter conditions, may be give interesting result in end milling machining process development of composite material cutting operation.

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