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A Review of Cutting Force and Optimization In Metal Cutting Process

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Abstract

Material removal process is one of the most important operations to obtain a required shape of the work materials. Among the several processes, machining process is considered as the most adequately used process to get the required shape of the work material. In that cutting forces are major predominant factor in the machining process. The knowledge on cutting forces generated during the end milling process is used to get the predefined productivity. In this paper, an attempt has been made to study the effect of cutting forces on vibration, tool wear and surface roughness during machining operations and different types of optimization techniques.

Keywords: Cutting Force, Vibration, Tool Wear, Optimizationand Metal Cutting Process.

Introduction

The influences of excessive cutting forces producepoor surface finish, high power consumption, less accuracy, temperature raises. It is the need to know the knowledge about the cutting forces for the following reasons like design the cutting tool, design calculations for jigs and fixtures, to estimate the machine power, determination of bearing loads and to avoid excessive distortion. Machining process is performed with single and multi point cutting tools in that rotary tool with multiple cutting edges is used in milling process. Peripheral milling and end milling are the two milling process that are mostly used in machining operations. Face milling is the surfaces that generate normal to the axis of rotation.In up milling process the feed direction is

opposite to the cutter rotation.The feed and cutter rotation are the same direction then the process is down milling. Cutting forces varies with respect to tool material, work piece materials and also the method of machining. In milling three kinds of cutting forces are generated such as axial force, radial force and tangential force. Fig.1 shows the three cutting force direction.

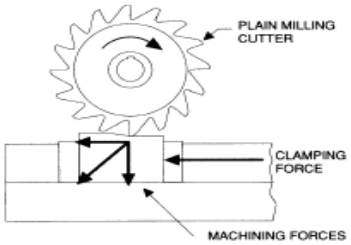

Figure 1: Cutting Forces

Measurement of cutting forces is mainly carried with dynamometers, but in olden days the hydraulic, pneumatic and strain gauge methods were also used. In milling process the cutting forces and cutting power vary continuously. Calculation of the instantaneous specific cutting power is based on measured cutting force or torque.

Influence of Process Parameters on Cutting Force

In milling process cutting forces are considered as one of the most important parameter, because the undesirable cutting force generated during the machining process. Normally cutting forces are generated in three axis while the material removal process takes place in milling machine. The minimum cutting forces are always recommended for machining operation.

In end milling process, induced cutting force such as infeed, cross feed and thrust forces are based on axis of rotation of the tool. Infeed, cross feed and thrust forces are acting tangential, normal and parallel to the rotating tool. Radial depth of cut effects the infeed and cross feed forces [1]. The influence of shearing cutting coefficients was affected not only based on the instantaneous chip thickness but also by considering cutting speed [2]. Cutting force harmonics are discussed by conducting experiment arrangement in vertical milling machine and the cutting force harmonics are obtained with the aid of simulation process. When the flank wear increases some of the cutting force harmonics gets increase and remaining harmonics are unchanged [3]. Increase in the feed rate and the depth of cut will increase the cutting force [4]. Complex shape geometry of uncut chips were analysed and based on cutting force models. The cutting forces acts on the left to the feed rate because on that time the side edges are under finishing process [5]. Fourier series and integral equations were used to obtain the dynamic milling force coefficients and vibrations occurs between the cutter and work material during the work [6].Chip formation force, ploughing force, particle fracture force were studied to predict the cutting force. Griffith theory was used to found theploughing force, particle fracture force and chip formation forces were determined based on the Merchant’s method [7].

Orthogonal cutting data's are used to model the chip flow based on the inclination of the pre machined surface. They concentrated the consumption of minimum cutting energy while machining complex-shapes [8]. With the help of the position of the centre of cutter, estimation of instantaneous uncut chip thickness can be calculated. This paper develops the systematic model for calculating cutting force coefficient and run out parameters [9]. Three dimensional force model gives the relationships between chip thickness, rake angle, cutting velocity, shear plane area and chip flow angle in milling process [10]. Discrete methods were used to analyse the time varying cutting forces that acts in flat end cylindrical milling process, the side and end cutting edges were taken into the account in order to analyse the cutting forces depends on the time variations. Based on this model the work piece and tool deflection also can be determined [11]. Fourier series method is one of the mathematical tools that used to analyse the sinusoidal compounds of the periodic functions [12].Deflection of tool causes the dimensional inaccuracy [13]. The contact area was most affected by the influenced factors of radial and axial depth of cut [14]. Genetic algorithm models were used for simulation of cutting forces and the experimental models were gathered based on the data acquisition system using LabVIEW.Data acquisition systems aid to presents the monitoring system [15]. By controlling the machining parameters the required cutting force can be obtain.The cutting force decreases with the increase of cutting speed due to the thermal softening which changes the shear angle [16]. FFT analyser were used to measure the cutting forces by considering the process variable as spindle speed, feed rate, depth of cut and noise radius [17,18]. Thermomechanical method and classical cutting coefficient methods were utilized to find local and global cutting forces [19].The face milling process where used under the dynamic registers cutting forces to modelling and prediction of the cutting forces. Depth of cut was one of the most influenced factors on the cutting force which affect the surface finish of the final product [20].The numerical solutions and statistical methods were used to obtain the predicted model of cutting forces in end milling process. [21]. Cutting forces were generated using the Pythagorean-hodograph curve [22].Cutting force acting on the spherical partswas studied using analytical method [23].

From the various literatures the importance of the cutting force on machining process were studied. Generally the cutting force model can be predicted based on analytical methods and experimentation. Cutting forces are mostly affected by process parameters such as cutting speed, feed rate, axial depth of cut, radial depth of cut, rake angle, nose radius, coated tool, diameter of tool, material of the tool and work pieceand helix angle. The presentwork describes the impact of cutting force in various metal cutting processes and explains the different optimization techniques.

Influence of Vibration on Cutting Force

Cutting force generated in metal cutting operation produce deflection of the part, tool and supply energy to the system which causes unstable vibration and excessive temperature. Vibrations are unfavourable to the tool and work material results in failure of tool and poor surface finish. Estimation of cutting force is necessary to control the vibration and deflection of tool [24].When end mill enters the specimen,

the full length of tooth takes the load and thus increases the cutting force. The shock load acts in driving mechanism of the machine inducechatter. The change of helical cutter instead of straight cutter reduces the vibration [1]. Feed rate and depth of cut are the main two parameters influence the vibration and cutting force. During lower cutting speed,the friction coefficient increase [25]. Vibration can measure by Micro electro mechanical system accelerometer. To check spindle vibration piezo electric transducer is employed. Fast Fourier transform analyser is utilized for derive the cutter path orientation [26].Vibration signal is collected through a microcontroller based data acquisition system monitoring the tool condition during machining. Machine condition monitoring system provides economic benefits in metal cutting process.Cutting force is most significant cutting signal for monitoring the tool condition[27]. Stability analysis of milling is difficult because of rotating tool, direction of chip load, cutting force, multiple teeth and multi degree of freedom of structure.Stability diagram used to predict the stability limit in terms of axial depth of cut [28].During metal cutting process,large amplitude of vibration is induced by cutting force which is produced on the tool in feed direction.Single spectrum analysis (SSA) was used to abstract and convert the raw signal of cutting tool vibrations [29]. The tool chatter and wear can estimate by investigating the cutting force and vibration signals acquired from various sensors[30].

Influence of Tool Wear on Cutting Force

Understanding of tool life needs to know about the mode of tool wear. Tool failure happens because of neither tool wear nor the plastic deformation. Based on the affected region of the tool it is classified at different types. Among these flank wear and crater wear are the most considered wear. Microscope or stylus tracing instruments are the mostly used for tool wear measuring. In case of lower cutting speeds adhesive and abrasive wear are the most significant [31].Performance of the tool depends on the connection between the tool and transferred layer on the wear land [32]. Different types of wear are chisel wear, crater wear, flank wear, outer corner wear, margin wear.Wearmechanism in flank face are abrasive and adhesive. This is due to rubbing action between the flank face and work piece since loss of clearance angle on the flank faces. In practice flank wear is used to obtain the tool life. [33].Tool wear is the makeover of gradual loss of tool material fromits original shape [34].Nose radius of the cutting tool gets reduced during the increase of flank wear resulting poor surface finish.High temperature and cutting force are the sources of adhesion of work material on tool face, thus accelerates the tool wear [35]. Tool tip wear mechanism is essential to study the tool wear. Coated tool instead of uncoated tool reduces the tool wear [36]. Addition of silicon carbide is harder and stiffer than the matrix material. Due to that machining become difficult [37]. The effect of cutting parameter on cutting force and tool deflection can be examined in time and frequency domain. Tool deflection curve helps to estimate the machining error [38]. Tool flank wear prediction was carried out on metal matrix composite in milling operation. Flank wear was mostly significant based on spindle speed and percentage of SiCp [39].

Optimization Methods

This study was employed to optimize the cutting force based on the nontraditional optimization techniques such as artificial neural network (ANN), genetic algorithm (GA) fuzzy logic system, ant colony algorithm, artificial bee colony algorithm, simulated annealing, particle swarm optimization and tabu search method. Objective function and the constrains are mandatory in all kind of optimization techniques.

A. Artificial Neural Network Approach

Neural networks and fuzzy set theory are two common soft computing methods. Artificial neural networks are self-effacing effort to model biological neural networks. An artificial neuron controls its output by scheming the weighted sum of inputs to represent the total strength of input signals and put on a suitable activation function of the sum. ANNs are mostly used for pattern recognition, pattern association and classification, constrained optimization and systems modelling with applications stretching from simple signal processing to medical diagnosis. ANN is an information processing system that displays similar performance of its biological analogue. It is fundamentally a mathematical model that simulates the human reasoning and neurobiology and that is based on the following assumptions.

1. Information processing happens in a number of simple elements named neurons.
2. Signals are communicated between neurons over connection links.
3. Each connection link has an allied weight that multiplies the signal transmitted.
4. Each neuron spread over an activation function to the incoming signal to regulate its output signal

The two main features of an ANN are: (i) The pattern of preparation of the neurons, namely the architecture of the network, which generally commands what type of problems can be dealt with; (ii) The method of determining the weights of the connections, either using a training algorithm generalizing the relative of input to output vectors-examples (supervised training) or deducinggroupings that are inherent to the data and generating an exemplar vector for each class that is created(unsupervised training).The most common type of ANNs that have been used in the literature examined is the feed forward ANN strained with some variation of the back propagation algorithm.

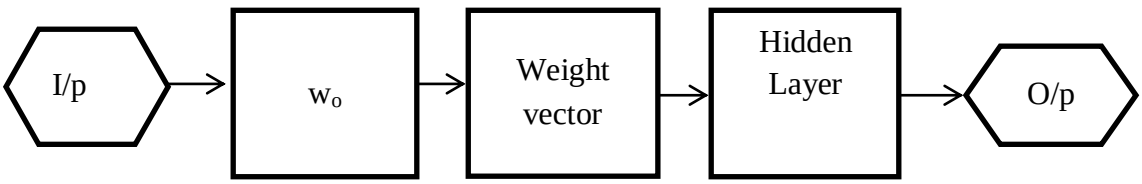

Figure 2: Operation of a Neural Network

The typical construction of these ANNs can be seen in Fig. 2. The neurons are organized in layers, i.e. the input layer, the hidden layer and the output layer.

Artificial neural network technique used to find the various cutting condition among the different cutting speeds, feed rates and depth of cuts for surface roughness, and the artificial immune systems was used to identify the best cutting condition to minimize the surface roughness [40]. Minimum tool wear can be achieved based on the ANN model [35].

B. Genetic Algorithm

The search algorithm based in the mechanics of natural selection and natural genetics is known as Genetic Algorithm (GA). They combined survival of the fittest among the string structures with some of the innovative flair of human search. The Genetic algorithm works with the major three process they are as Reproduction, Crossover, Mutation in addition to this major process the sub process like population chromosomes are helps the fitness test.

Reproduction: The chromosomes are selected based on the reproduction operator. In reproduction process according their fitness values the individual strings are copied in to a separate string called as mating pool. A large number of copies and mating pool is formed based on good strings in a population are probabilistically assigned.

Crossover: Good strings from the previous generations are enriched after reproduction only but there is no new strings availability. In order to create a new string the crossover operators is applied. These crossover operators are mainly used to get better string as compared to previous string. The crossover probability is used to control the total number of participative string in crossover. The parent string and the children strings are the two strings participating in the crossover operation, in this the resulting strings are known as children string.

Mutation: changing of chromosomes from 0 to 1 or vice versa on a bit by bit basis based on random modification is known as mutation. The mutation keeps the diversity in the given population. After applying the genetic algorithm operators the new set of population is created.

The genetic algorithm for optimization problem is given as follows

Step 1: Mention the name of objective function in MATLAB script window

Step 2: enter the cutting force equation based on the created objective function, the cutting force equations are need to be entered individually for infeed force, crossfeed force and the thrust force.

Step 3: select the optimization tool from the application tool bar available in MATLAB.

Step 4: select the Genetic algorithm as a solver for the required objective function.

Step 5: enter the number of variables used in the objective function and also enter the lower and upper boundary limits tor the machining parameters.

Step 6: set the all required constrains including population type, reproduction, crossover, mutation

Step 7: start the iteration and get the values of objective function values and optimal cutting forces.

The non-conventional optimization methods such as Genetic Algorithm, Ant Colony Algorithm, Tabu search method and Particle swarm optimization for optimizing machining parameters to maximizing the profit in milling operations [41]. Cutting force was optimized based on the process parameters in genetic algorithm [16].The optimum cutting parameters to obtain the minimum surface roughness using Genetic algorithm method was employed. The obtained optimization result of genetic algorithms was verified by conducting the experiments based on the optimum values of cutting parameters and measuring the surface roughness [42]. Genetic algorithm based optimization of machining parameters were studied to minimize the temperature rise in end milling of AL 6063 [43].

C. Ant Colony Algorithm

The ant colony algorithm is an algorithm for finding optimal paths that is based on the performance of ants penetrating for food. At first, the ants strollrandomly. When an ant catches a source of food, it walks back to the colony partingmarkersthat show the path has food. When other ants come transversely the markers, they are likely to follow the path with a confident probability. They then inhabit the path with their own markers as they take the food back. As more ants find the path, it gets tougher until there are a couple streams of ants roaming to various food sources near the colony. Because the ants fall pheromones every time they bring food, reduced paths are more probable to be stronger, hence optimizing the "solution." In the interim, some ants are still randomly analysis for nearer food sources. Once the food source is worn-out, the route is no longer populated with pheromones and gradually decays. Because the ant-colony works on a very active system, the ant colony algorithm works very well in graphs with altering topologies Fig 3. The ant colony algorithm result wasequated with the simulated annealing and genetic algorithm. The ant colony algorithm is based metaheuristic it gives the superior solution as compared other two methods, this method was problem independent therefore the variation can be take place easily [44]. Ant colony algorithm was used to maximize the profit based on the machining parameters and relative study was carried with GA, PSO and tabu search method [40].

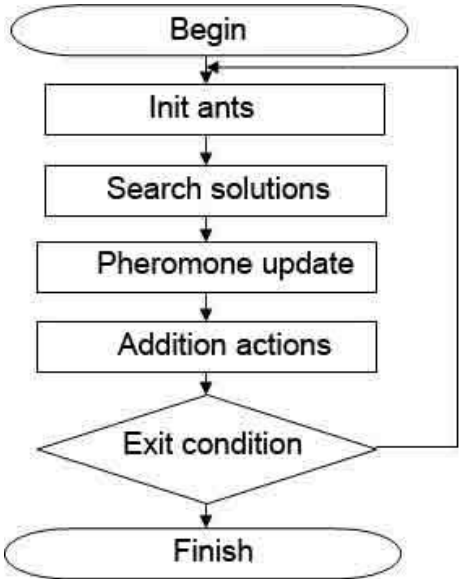

Figure 3: Ant Colony Algorithms

D. Artificial Bee Colony Algorithm

The artificial bee colony optimization algorithm mechanism based on the population based random search algorithm with the concept of bees food searching methods. The ABC algorithm is developed by Dervis Karaboga in the year of 2005, these ABC algorithms is mainly founded on the honey beesperformance.

The ABC algorithm is one of the most modest optimization methods when associated with the optimization methods of Differential Progression algorithm and the particle swarm methods, because the ABC algorithms used the elementary parameter such as size of colony, cycle number. The bees are probing foods at more than one places but the best nectar is chosen by the quality and quantity presented in each food source area. ABC algorithm is forms based on the following process Size of bee colony = number of bees convenience (normally used above 20 and below 400). Number of food sources = sum of employee bees, but ordinarily the number of food sources are initiate by half of the bee colony size.

Position of food source = potential solution of the problems or the groupings of input variables.

Food source nectar = quality of the solution based on the inputs.

The Artificial bee colony algorithm based on the three levels like the bees called as employee bees, onlooker bees, scout bees.

Initialize

Repeat

a) Place the employed bees on the food bases in the remembrance;

b) Place the onlooker bees on the food sources in the memory;
c) Send the scouts to the search area for discovering new food sources.

Until (Requirements Are Met)

The Artificial Bee Colony algorithms is the powerful and efficient tool for optimization compared with genetic Algorithm(GA), Particle swarm optimization (PSO) and he particle swarm Inspired Evolutionary algorithm(PS-EA) [45].The standard and modified methods of artificial bee colony algorithm are analyzed based on their performance. Finally this paper concludes that the standard ABC algorithms are best as comparing with the modified ABC algorithm [46]. The multi objective optimization was carried out by using artificial bee colony algorithm which describes the ABC algorithm into four phase's initial phase, employee bee phase, onlooker bee phase and scout bee phase. This paper presents the optimization of surface roughness and material removal rate in electrical discharge machine based on the process parameters of pulse on time, pulse off time, discharge current and voltage. Applying the greedy selection process to the employee bees the best population solution was used finally memorizing the best solution. [47].

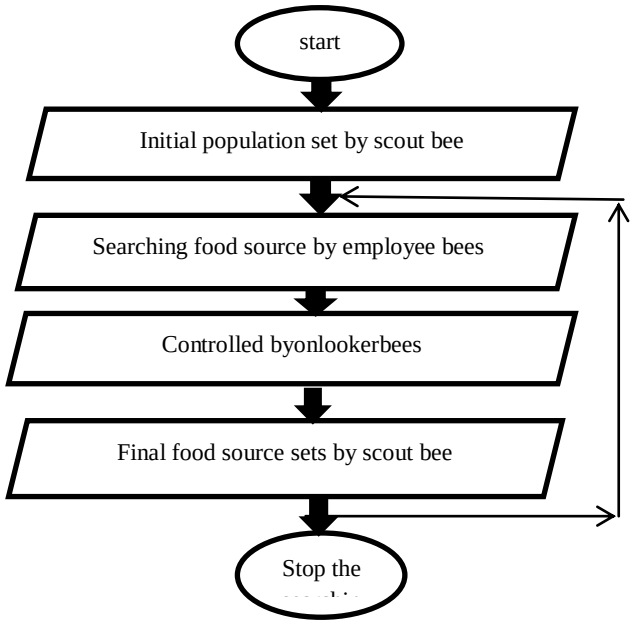

Figure 4: ABC algorithm

The artificial bee colony algorithm works with the flow drawing Fig 4. The initial population is established by the scout bee, then the employee bees are examining the food one or more sources based on arbitrary search. These employee bees are organized by onlooker bees, these onlooker bees are permits the information about the

search to scout bee. Then the final food source localities are secure by scout bee based on the data gathered from the employee bees and onlooker bees.

E. Simulated Annealing

Solving unconstraint and boundary constrain problems for optimization the simulated annealing methods is one of the greatest optimization methods between the other optimization methods. The new point is randomly made in simulated annealing algorithm for each iteration. The probability distribution along with the scale proportional on temperature used to find the distance of the new point generated from the current point, the simulated annealing algorithm always lower the objective for all new points but some time they may raise the objective with a certain probability points.

Simulated annealing works based on the following four important terms objective function, temperature, annealing parameters, reannealing.

Steps in simulated annealing algorithm

1. The trail point is needed to be set with the distance distribution as a function with the annealing function.
2. The new point is compared with the current point in order to verify whether the new point is good as compared with current point or not. If the new point is not good as the current point then the algorithm still search the next point. If the new point is as good as the current point then the new point is marked as the next point.
3. To store the best point found, the algorithm lowers the temperature systematically.to update the temperature the specific function available in this algorithm called TemperatureFcn, the remaining annealing parameters are keep same as the iteration number until the reannealing process takes place.
4. The reannealing process takes after it accepts the reannealing interval points, the lower values than the iteration number are set by the annealing parameters for reannealing. These reannealing parameters based on the estimated values of gradients of each dimension.
5. When the average changes in objective function are found in very small relative to the tolerance function otherwise when it reaches any stopping criterion.

The simulated annealing based optimization in turning process was used and compared with other optimization methods [43].Optimum process parameters are achieved based on the simulated annealing in multi pass milling process [48]. Minimum surface roughness was obtained based on the simulated annealing optimization [49]. Slow cooling process gives more arrangements in simulated annealing method [50].

F. Particle Swarm Optimization

Particle swarm optimization methods was introduced for a concept of answering nonlinear functions optimization problems, the particle swarm optimization methods works based on bird clustering, fish schooling and swarm theory. In this optimization methodology in order to get optimum result particles are searching, so that each

particle moving in a velocity. Each particle should recollect their position or location where they found the best results till the end of the searching process, this is known as personal fit or personal best anyway this particle searching needsframework layout (figuring out) to identify or to know about where to search.

The particles elaborate in probing they have the habit of substituting the information within theneighbor particles what they identified so for, the particle has to move to the new situation based on the time step, these time steps are familiar based on adjusting the velocity of the particle. In particle swarm optimization the neighborhood particles are mostly selected as a circular path. Each particleadjusts their position according to their individual comfortable, the following parameters are considered as the common parameters in particle swarm optimization.

Number of particles normally 10 to 50 particles is used for best optimization need to give the importance of personal best and also the importance of neighborhood best.Normally the sum of personal best and neighborhood best are considered as 4.Velocity is mentioned in four different terms those are too low, too slow, too highand too unstable.

Vikas Pare et al [51] proposed the particle swarm optimization methods to minimize the surface roughness based on the four input variables such as cutting speed, feed rate, radial rake angle and depth of cut in end milling process. The evolutionary technique is applied for efficient optimization of high speed end milling based on process parameters [52].The swarm intelligent techniques for optimization were used to get the optimal cutting conditions. By considering the recommended cutting condition neural prediction model was developed in the 1st phase of optimization, the PSO algorithm was developed based on the swarm of particles on the cutting forces during in the second phase of optimization. The algorithm steps are given as in Fig 5.

Step1. Initial population is generated based on considering random search method.

Step2. Population evaluations are tales place by searching point of each particle.

Step3. Identify the best particle position if not so then modify particle location, modify the searching agents speed.

Step4. Repeat the step 3 up to identifying the best optimal condition.

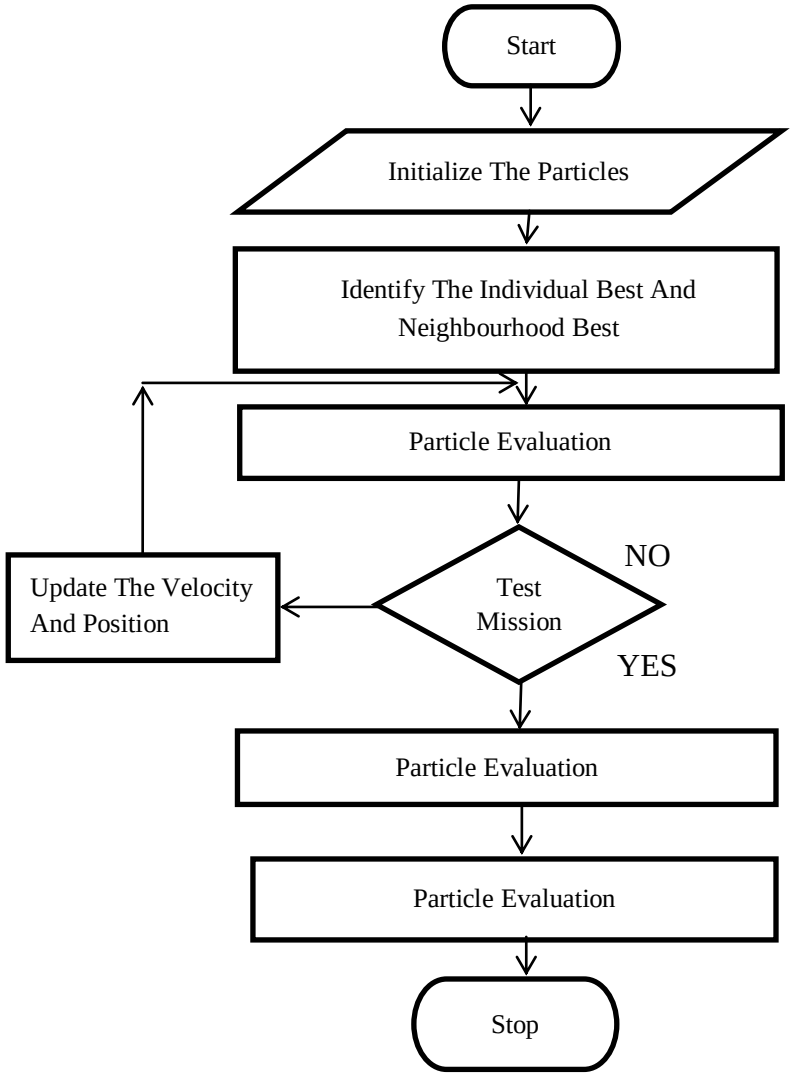

Figure 5: PSO Algorithm

G. Tabu Srarch Method

The local search strategy with the flexible memory structure is known as tabu search. The Branch and Bound and the simulated annealing re the two major categories in that the Branch and Bound having a rigid memory structure and there is no memory structure for simulated annealing. Responsive exploration strategies and the adaptive memories are the two prominent features of tabu search. The basic steps involved in tabu search are described as follows.

Detect the recent location solution.

Produce the adjoining solution. Among the several neighboring solution find the best neighboring solution.

Check the designated solution for accessibility.
If not find additional best neighboring solution.
Repeat the checking of accessibility until it getsmanageable
If accessible accept the solution and replace that solution as current solution.

Discussed the optimization of the milling process parameters based on the tabu search method[40].The parameters used in tabu search methods are recorded as local search procedure, neighboring structure, aspiration conditions, form tabu movements, growth tabu movements, increase the size of tabu list and stopping rule.

H. Fuzzy Logic Approach

Fuzzy logic is the conventional of mathematical principle for knowledge representation and reasoning built on degrees of membership.Fuzzy inference systems (FIS) are moreover known as fuzzy-rule based system, fuzzy models and fuzzy associative remembrances (FAM). Essentially, a fuzzy inference system is composed of five functional blocks [44].

The rules in fuzzy sets are typically if-then rules.Membership functions are defines with the data base in fuzzy sets are used in fuzzy rules.The inference processes on the rules are performed by decision making unit. Fig 6 gives the simple block representation of Fuzzy system.

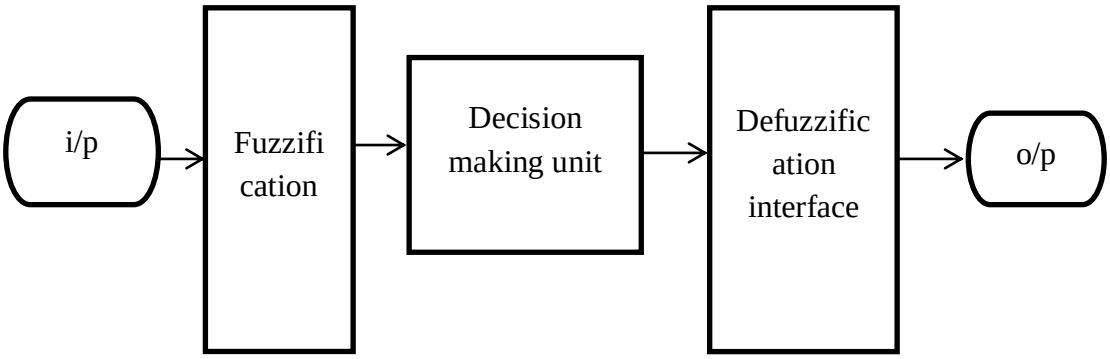

Figure 6: Fuzzy inference system

Alteration of the crisp inputs variables in to the linguistic values are inference with fuzzification. The inverse operations of fuzzification i.e. transforming fuzzy results of the suggestion into the crisp output are termed as defuzzificationProcess parameter optimization with the different methods was discussed and the number of study or research made by different optimization methods is given in the Fig 7. Among these methods Genetic algorithm, Taguchi and particle swarm optimization methods are frequently used methods.

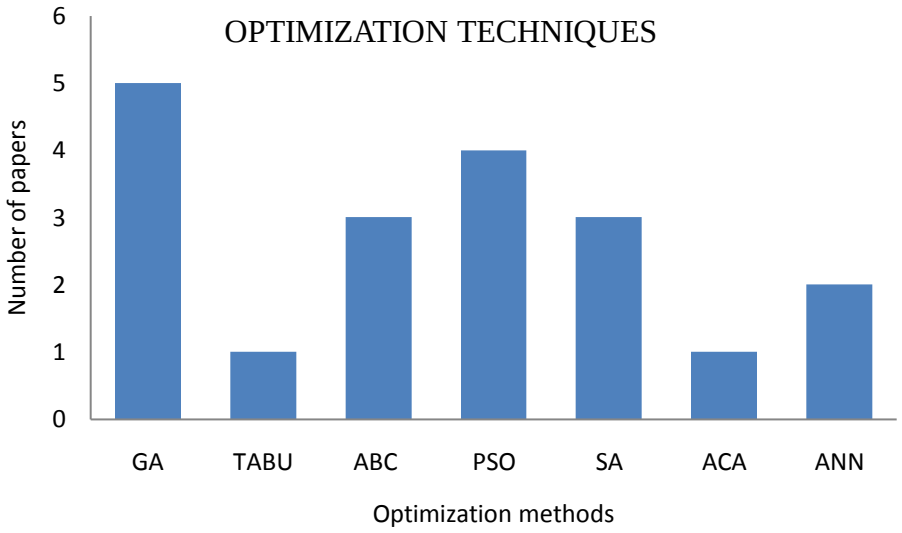

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Figure 7: Methods of Optimization Vs Number of papers

Conclusion

Based on the review of various study on machining process the following conclusions are formulated.

- Prediction of cutting force can be done with analytical method and experimental method.
- Cutting forces are mostly affected by process parameters such as cutting speed, axial and radial depth of cut, rake angle, nose angle and helix angle.
- Cutting forces decreasing with increase in cutting speed.
- Minimum vibration and cutting force provide less tool wear.
- High temperature and cutting force accelerates the tool wear.
- Different methods of optimization techniques are analysedto obtain best quality and reduce rework.

Abbreviations

RSM - Response surface methodology
ANN - Artificial neural network
ABC - Artificial Bee colony algorithm
GA - Genetic Algorithm
TABU - Tabu search method
PSO -Particle swarm optimization
SA - Simulated Annealing
ACA - Ant Colony algorithm

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