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State-Of-The-Art Optimization Techniques for Complex Machining Processes: A Review

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Abstract: The main objective in machining operation is to produce a product with high quality and competitive price. Machining of advance materials is an important topic in current researchers on manufacturing processes. To determine an optimum cutting parameters is the prime requirement in the machinability study of super alloys. To improve quality of machined surface, the cutting tool must have its ability to retain severe cutting conditions all the times. To keep tool in a good condition, parametric optimization of spindle speed, feed rate, tool geometry is on the top priority. The industry has a demand of new materials like super alloys which are hard in nature and are difficult to machine. Effective machining without compromise product surface quality by specific manufacturing processes showed a new direction to the industrial world. Many conventional and unconventional manufacturing processes are used by the industrial sectors like marine, nuclear, petrochemical, aerospace, medical etc. These processes are having many process parameters and to select particular parameter is very critical task as it has considerable impact on process performance. As the process parameters are in large, random selection of parameters will not give desired output. If the desired objectives are in a large number, then it is very crucial situation. The advance optimization techniques can handle such situation effectively for process parametric optimization. In this paper, advance optimization techniques of parametric optimization for complex manufacturing processes have been discussed.
Keywords: Electric discharge machining, drilling process, turning process, Optimization techniques

I. INTRODUCTION

A. Manufacturing processes and requirement of its modeling and optimization

In today's scenario of manufacturing world, for getting quality products through effective machining with competitive price, it's very essential to select the optimum machining parameters associated with that particular process [1]. Process modeling and optimization using specific algorithm is an effective way of eliminating problem by establishing the relationship between the performance of the processes and its control input parameters [2]. The traditional optimization techniques used to solve problem of machining processes are successful in some extent but slow at junction and take more computing time [3]. The fundamental machining processes are the base of any industry and it is account of a large volume of material removal. The demand for machining of intricate shape and complex geometry and difficult to machine materials with required tolerances and surface quality has turned in to a requirement of many conventional and unconventional machining processes. Performance of such processes are affected by many factors and any change in parameter can influence a process in a complex mode. Many variables are complex and stochastic in nature of the process, so for getting an optimum solution with advance manufacturing processes with skilled person also bit difficult. In the following session, detailed literature review on the parametric optimization has been described.

The conventional and unconventional machining processes which are on high demand in the industrial sectors are precession turning, CNC assisted drilling, milling, grinding, electric discharge machining (EDM), wire electric discharge machining (WEDM), abrasive jet machining (AJM), electrochemical machining (ECM), laser beam machining (LBM) and these all machining processes with special attachment and micro machining. These all processes have their specific working principle by which they use the properties of materials which make them appropriate for practical application and they have some limitations also. These processes are associated with a variety of process parameters and to select them is very critical for machining processes which may adversely affect to the functionality of processes. As there are a large number of process parameters are involved, random selection of these parameters will not give the desired output. In such cases effective use of advance optimization techniques serve the purpose well. Researchers have developed and applied a different optimization technique like genetic algorithm (GA), particle swarm optimization (PSO), simulated annealing (SA), artificial bee colony (ABC) etc. and these advance techniques had shown their effectiveness for the parametric optimization in the field of manufacturing processes. Modeling and parametric optimization of machining processes through advance optimization techniques has proved as a benchmark in the manufacturing sectors and due to this reason the researchers are making use of these technique for better output. In this paper such research work is highlighted [1].

II. REVIEW OF COMPLEX MACHINING PROCESSES

A. Parametric optimization of an electric discharge machining process

The EDM process for machining of difficult to machine materials like nickel and titanium alloy super alloys, various composites, high speed steel and ceramic materials is being used by modern industrial sector. The machine is now in its newer version called wire electric discharge machining and micro EDM to make process more efficient. It involves a large number of input parameters like discharge current, duty cycle, pulse-on time, pulse-off time, flushing pressure of dielectric fluid, polarity of electrode, were fed rate, wire tension, servo voltage etc. In the manufacturing industry, the parameter setting is generally adjusted by operator experience or by machine data handbook. Due to this, the optimum parameter setting is not achievable and cause reduction in production with poor quality of machined surface and higher cost. With the help of process parameter optimization, the production rate can be increased without compromise the quality of product along with reduced rejection rate so it will turn in to reduction is cost [1]. Kumar et al. [4] showed the importance of EDM process input parameters. The parameters have the significant influence on output responses such as material removal rate, surface roughness, tool wear etc. For getting success, the control over the setting of these parameters is extremely essential. The process has the objective function of maximization of MRR and simultaneously minimization of tool wear rate. If we can increase an intensity of current from low to high will significantly increase MRR but same time the surface roughness will also increase. Trial and error method to set these parameters may give good result for one objective at a time so production rate will be reduced with poor quality. Hence optimum parametric setting is required for the process by which contradictory objectives are satisfy. This is possible by choosing an appropriate technique of optimization. Also efforts should be made in the direction of getting a universal optimum solution.

It is evident that the researchers have done a lot of work in the direction of parametric optimization of EDM process. Most of them have adopted the Taguchi technique for getting optimum combination of parameters and to check their effect on the output responses. The advance optimization technique like genetic algorithm (GA) and its form like ABC, PSO, SA, etc. Some of them are combined application like use of ANN with Taguchi method which are used by researchers. It was noted that the process constraints were not considered in majority of the cases. Hence it is expected to study the effect of one input parameter on variety of output responses by considering all the parameters with process constraints with the help of mathematical modeling. Combined effect of various input parameters on the process response is also required to be studied simultaneously. More and consistent use of recent optimization techniques is also required specially to attempt multi-objective problems of EDM process. Table-I shows the literature review related to optimization of EDM process [1].

B. Parametric optimization of a drilling process

To produce a circular hole in the work-piece by using rotating tool called drill, the machine used for this purpose is called a drilling machine. The twist drill is used extensively in the manufacturing industry. The peripheral speed of the drill is called cutting speed, the movement of the drill towards work piece is called feed and drill radius is the depth of cut are the cutting parameters. To achieve the production cost and time minimum, the cutting parameters are optimized [17]. Because of a traditional metal removing process and its versatility, the drilling process has drawn concentration from automotive, aerospace, machine tools manufacturing industries. It is the first machining operation performed in hole cutting process. Drilling is a thermo-mechanical process in which heat is generated due to friction and plastic deformation of the work piece material so temperature at the cutting zone increases because of heat generation and accumulation [24]. Due to which the drilling process is rather familiar as a complex machining process for advance materials. Researchers have investigated various drilling parameters like cutting speed, feed, tool material, tool angles tool diameter etc. on machining output responses like machined surface roughness, flank wear of drill tool, cutting forces and vibrations. In the metal cutting industry, the tool vibration is very critical parameter which adversely effect on tool life, surface finish and after all production cost. Hence it is desired to minimize its effect on machining characteristics. In the drilling process, chip formation is not visible and the drill vibration is difficult to control. In addition to this, due to tool work piece interaction, a high temperature is generated in the machining of super alloys which turns in to formation of built up edge on the tool surface and leads to premature tool failure. It is required to optimize the drilling parameters for obtaining minimum surface roughness, tool wear, energy consumption and to maximize metal removal rate as well as tool life etc. Researchers have adopted and developed many traditional and advanced optimization technique for the purpose of parametric optimization [17]. The mechanism which is responsible for the generation of surface roughness is complex in nature and dependent on the applied process. The drilling tools and process parameters used may affect the quality of surface roughness. To analyse surface roughness, either mathematical or statistical tools are used and sometimes operators are used trial and error method to select drilling parameters which is actually not giving desired results. Many researchers have investigated and developed some techniques for modeling and optimization of drilling process. It is presented in a tabular form along with necessary details for understating in table number-II.

C. Parametric optimization of a turning process

In the turning process, parameters like cutting speed, feed rate, depth of cut, tool geometry, cutting tool materials and cutting fluid or coolant have a major impact on the productivity, tool life, material removal rate(MRR), cutting forces and the quality of machined surface roughness. The machine tools are suffering from high wear and tear with vibrations during hard turning operations and the reason is higher cutting velocity. To eliminate this problem, a special turning operation is proposed with an application of two single point cutting tools. This developed process is familiar with duplex turning process. It is a novel concept to minimize number of passes and exclude the secondary finish cut operation of the component. The aim of this process is to improve machined surface quality, productivity and reduce pass number. It is more complex due to introduction of two tool application in turning. In this context, it is essential to select better combination of parameters. Researchers had applied various mathematical modeling and optimization techniques for the eliminating the problem of costing, tooling and productivity. They have applied Response Surface Methodology and Taguchi method for this complex process. [29]. The super alloys materials like nickel and titanium alloy are extensively used in aerospace, automotive, medical and many industries. As they are famous for difficult to machine materials because of their unfavourable properties like low thermal conductivity, lower modulus of elasticity, chemical reaction with majority of tool materials at higher temperature, higher strength at elevated temperature. These characteristics result in high tool wear, deteriorate surface integrity, higher machining cost. The study to improve machinability of such alloys are major interest of many researchers for last several years.

TABLE I

REVIEW OF PROCESS PARAMETRIC OPTIMIZATION FOR THE EDM AND ITS ASSOCIATED PROCESSES.

Sr.No	*Year/Author(s)*	*Machining process*	*Work material*	*Input parameters*	*Objectives/Responses*	*Optimization technique applied*	*Important Observation*
1	2012/Lin et al. [5]	Micro-EDM	SK3 carbon tool steel	Peak current, Pulse-on time, Pulse-off time, Electrode rotation speed	Electrode wear, MRR, Overcut	RSM	Peak current was the most significant variable affecting the process performance
2	2016/Satpathy et al.[6]	EDM	Al-20 % SiCp Metal Matrix Composite	Input current , Pulse on time , Duty cycle, Gap voltage	MRR, Tool wear rate	PCA and TOPSIS Method	The combined method was effective towards output responses.
3	2016/Guo et al.[7]	EDM drilling	Nickel base super alloys	Peak current, Pulse duration, Duty factor, and Flushing pressure	Machining time (MT), Electrode wear (EW)	Gray relational analysis	The gray relational grade index improves from 0.7393 to 0.7785.
4	2016/Aich et al.[8]	EDM	High speed steel cutting tool	Current, Pulse on time, Pulse off time	MRR, Average Surface Roughness	Modified TLBO	Modified TLBO,found more efficient than modified PSO technique
5	2016/Selvarajan et al. [9]	EDM	Si3N4–TiN Composite	Current, Pulse on time, Pulse off time, Dielectric flushing pressure	MRR,Circularity, Cylindricity, Perpendicularity	Taguchi DOE	The sparking process responses can be effectively improved
6	2016/Rahang et al.[10]	EDM	Aluminium	Compact Load , Peak current , Pulse on-time	Tool wear rate , Material transfer rate, Surface roughness , Edge deviation	Taguchi design of experiment.	Minimum Ra of 4.5 mm and minimum edge deviation of 37.29 mm is achieved
7	2016/Rangasamy et al.[11]	EDM	Al 4032 alloy reinforced with Zrb2 and Tib2	Pulse ON, Pulse OFF, Current	MRR, TWR	Taguchi method	Taguchi method is effective towards the output responses
8	2017/Lee et al. [12]	Die Sinking EDM	En31 Tool Steel	Duty cycle, Voltage, Pulse on time, Spark gap	Surface roughess, Tool wear rate	Taguchi method, Utility concept	The study reveals the best machine setting & optimum values of process parameters
9	2017/Meena et al.[13]	Micro-EDM	Cp titanium	Current, Frequency, Pulse width	MRR, Electrode wear rate, Overcut	Taguchi . Grey relation analysis	Grey relational analysis is effective for getting the desired results
10	2017/Ubaid et al. [14]	EDM	Stainless steel 304(ASTM A 240)	Pulse-on time Pulse-off time, Sprak gap, Dishcarge current, Gap volrage, Polarity	MRR, EWR	Design of Experiments, fuzzy logic, and ANOVA methods.	Pulse off Time being the most significant parameter
11	2017/Bhosle et al. [15]	Micro-EDM	Inconel 600 alloy	Voltage, capacitance, EDM feedrate, Pulse-on time and Pulse-off time	The material removal rate, Taper angle, overcut and diameteral variance	ANOVA and Grey relational analyses.	With this approach, the form accuracy and surface quality of microholes can be improved effectively
12	2017/Mohanty et al. [16]	EDM	Inconel 718 super alloy	Open circuit voltage, Discharge current, Pulse-on-time, Duty factor, Flushing pressure, Electrode material	MRR, TWR, Surface roughness, Radial overcut	Utility concept and QPSO algorithm	Results demonstrate the elegance of QPSO in terms of convergence and computational effort

TABLE III
REVIEW OF PROCESS PARAMETRIC OPTIMIZATION FOR THE TURNING AND ITS ASSOCIATED PROCESSES.

Sr.No	*Year/Author(s)*	*Machining process*	*Work material*	*Input parameters*	*Objectives/Responses*	*Optimization technique applied*	*Important Observation*
1	2017/Aravind et al.[27]	Turning	11sMn30 Alloy	Cutting speed, Feed rate, Depth of cut	Process capability index(Cpk)	Taguchi approach	The feed rate and cutting speed have equal significance in determining the surface roughness
2	2017/Raman et al. [28]	Turning	EN 353 alloy steel	Nose radius, Cutting speed, feed rate and depth of cut	Energy effciency, Ra, MRR	Taguchi-method, AHP, TOPSIS, Entropy-method	Optimization method plays important role in decision making in multi objective optimization.
3	2017/Yadav et al. [29]	Turning	AISI 1040	Cutting velocity, feed rate, primary depth-of-cut and secondary depth-of-cut	Surface roughness	Taguchi method, MRR	Significant improvement was found in surface finish with hybrid approach as compared to the Taguchi analysis.
4	2016/Bilga et al. [30]	Turning	EN 353 alloy steel	Cutting speed, Feed rate, Depth of cut, Nose radius	Energy efficiency, Active energy consumed by the machine, Power factor	Taguchi method, ANOVA	Improvement of 61.776%, 57.025% and 7.49%, respectively
5	2017/Satyanarayana et al. [31]	High speed Turning	Inconel 718	Cutting speed, Feed, Depth of cut	Minimize tool wear	ANOVA, Genetic Algorithm (GA)	Satisfactory results are obtained through this research work and can be adopted in Industries
6	2017/D'Mello et al.[32]	High speed Turning	Ti-6Al-4V	Cutting speed, Feed rate, Depth of cut,Tool flank wear	Surface roughness	Particle swarm optimization, Bat algorithm, Firefly algorithm	BA produces better optimization, when compared to FA and PSO
7	2014/Bouacha et al.[33]	Hard Turning	AISI 52100 bearing steel	Cutting speed, Feed rate, Depth of cut, Cutting time	Tool wear, Surface roughness, Cutting forces, Metal volume removed	Multi-objective optimization, Genetic algorithm, Grey-Taguchi,RSM	GA technique seems to be the most advantageous approach
8	2014/Koyee et al.[34]	Turning	Duplex stainless steels	Cutting parameters, Cutting fluids, Axial length of cuts	Percentage increase in radial cutting force, Effective cutting power , Maximum tool flank wear, Chip volume ratio	RSM, TOPSIS, Cuckoo search	Optimization methods were significantly effective on responses
9	2017/Bagaber et al. [35]	Turning	Stainless steel 316	Cutting speed, Feed, Depth of cut	Power consumed, Surface roughness, Tool wear	RSM	The proposed method is effectively reduced the effects and costs of the machining process
10	2017/l Chabbi et al. [36]	Turning	Polyoxymethylene polymer	Cutting speed,Feed, Depth of cut	Minimum surface roughness as well as cutting force, Cutting power	RSM, ANOVA	RSM serves the purpose for geeting desired results

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direction is the high speed machining which is drawing attention as it results in quality machined surface without any stresses generated in it. Artificial neural network (ANN), particle swarm optimization (PSO), bat algorithm (BA) and firefly algorithm (FA) have been used by researchers for getting better results in turning process [32]. In the manufacturing industry, the turning process is an important and used on large scale. The metal machining study involve with the tool types, work piece materials and setting of machine parameter. The turning process is growing fast from last several years for getting specific objectives. To achieve the objectives, selection of optimum parameters is most important. Turing process involves a large number of input variables like cutting speed, feed rate, depth of cut, tool material and types, geometry, cutting fluid, etc. and output variables like tool life, surface roughness, cutting zone temperature, energy utilization etc. Randomly selection of input parameters cannot give desired objectives. Each output response should be considered as a set of input variable [35]. Parametric optimization of cutting process is complex and requires depth understanding of machining and empirical notations related to tool life, surface finish, power consumption etc. [37]. A single objective optimization determines the value of a controllable parameter which gives the highest value of specific response like metal removal rate. For the machining process having complex nature, single objective optimization can’t have broader optimum cutting conditions. In this context various different conflicting objectives must be concurrently optimized [1]. The review mentioned in the table number-III is showing contribution of various authors related to optimization of turning process.

III.CONCLUSIONS

In this paper, the complex machining processes like electric discharge machining (EDM), turning process and drilling process are discussed with the reference to an application of state-of-the-art optimization techniques. The literature review related to parametric optimization of machining processes have been summarised. The input and output parameters, work material and advance optimization techniques used by researchers along with observations have been described. Following are some conclusions made on the basis of literature review.

A. The complex machining processes mentioned in this paper are having a lot of industrial applications and they are on demand in automotive sectors, medical, aerospace, and biomedical for manufacturing of parts with intricate and complex geometry.
B. Researchers have done work more on electric discharge machining compare to other machining processes. In EDM and related processes, the Taguchi method and RSM were used more for research work. Genetic algorithm (GA) and artificial neural network (ANN) were also used with some modifications.
C. Researches now have been started to use advance optimization techniques like teaching learning algorithm (TLBO). Research work on variety of materials had done in EDM, turning and drilling processes like ceramics, super alloys, hard materials, composites etc. A wide spectrum of scope is there in the field of optimization for the micro machining and nano finishing processes.

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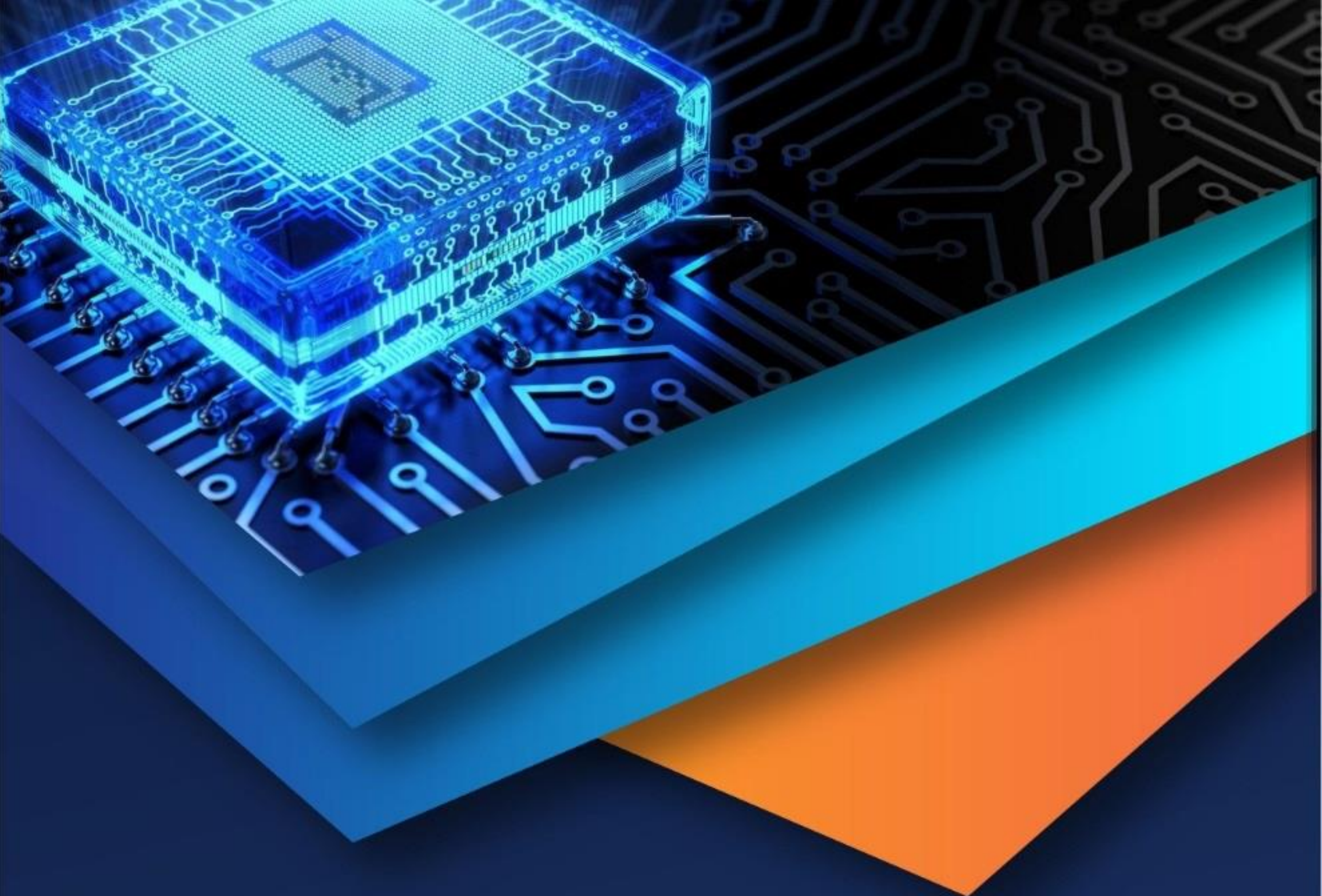

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