



A review on Optimization of material removal rate in micro-drilling process

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Abstract: Most of automotive components are manufactured using a conventional machining process, such as turning, drilling, milling, shaping and planning, etc. Micro-hole drilling is the precision hole drilling technology to use in manufacturing and workshop. Micro drilling is one of the most fundamental machines technologies and it is moving high precision and high spindle speed application in manufacturing field and increasing productivity and quality. It is an important machining process having attractive applications like Printed circuit boards, Fuel injection nozzles, Watch parts, Camera parts, Medical needles, Aeronautics., Mobile phones, Computers etc. This will be benefited by a comprehensive literature review of drilling processes and optimization. This paper presents a literature review on micro-drilling processes, optimization of MRR depending upon various parameters for other machining processes through taguchi method and fuzzy optimization.

Keywords: Micro-drilling, Cutting tool, Material removal rate, Taguchi, Fuzzy

I. Introduction

Drilling is one of the basic technology. Micro Drilling is high precision process for smaller holes below 1mm. It is used for the purpose increasing quality of special parts and items. The price of a micro-drill cutting tool itself is relatively low, the costs caused by tool failures are considerably higher. Material removal rate is one of the major manufacturing goal in machining operations. Taguchi method is a well known experiment design method applied in many industries to optimize quality characteristics through the setting of design parameters with orthogonal array, followed by optimization of the Fuzzy parametric deduction to improve MRR.

II. Micro Drilling

Micro drilling small diameter presents greater problems since coolant fed drills cannot be used and high spindle speeds are required. High spindle speeds also require the use of balanced tool holders. Micro drilling is characterized not just by small drills but also a method for precise rotation of the micro drill and a special drilling cycle. In addition, the walls of a micro drilled hole are among the smoothest surfaces produced by conventional processes. This is largely due to the special drilling cycle called a peck cycle. The smallest micro drills are of the spade type. The drills do not have helical flutes as do conventional drills and this makes chip removal from the hole more difficult. Drills with a diameter of 50 micrometers and larger can be made as twist drills. Drills smaller than this are exclusively of the spade type because of the difficulty in fabricating a twist drill of this size.[2]

Drilling may affect the mechanical properties of the work piece by creating low residual stresses around the hole opening and a very thin layer of highly stressed and disturbed material on the newly formed surface. This causes the work piece to become more susceptible to corrosion at the stressed surface. A finish operation may be done to avoid the corrosion. Zinc plating or any other standard finish operation of 14 to 20 μm can be done which helps to avoid any sort of corrosion.

For fluted drill bits, any chips are removed via the flutes. Chips may be long spirals or small flakes, depending on the material, and process parameters. The type of chips formed can be an indicator of the machinability of the material, with long gummy chips reducing machinability.[8]

The recommended speeds and feeds for micro drilling are as varied as the materials which can be drilled. Micro drilling is not generally a high speed process since dwelling of the drill at the bottom of the hole can cause hardening of the work piece leading to increased drilling forces. For most metals, typical spindle speeds are in the 2000 to 4000 rpm range and feeds are in the range of a micrometer per revolution, or so. Care must be taken when drilling plastics to avoid melting of the material which can lead to adhesion of the plastic to the drill. This can cause drill breakage or poor sidewall smoothness.[7]

Azlan Abdul Rahman, Azuddin Mamat (2009) A study on optimum drilling parameter for HSS drilling tool in micro-drilling (0.5 mm to 1.0) processes in order to find the best drilling parameter for brass as a work piece material. This work had given following outputs: 1) The value of surface roughness are mostly influenced by spindle speed and feed rate. If the value of these spindle and feed rate increases, the value of surface roughness will decrease. The tool diameter gives less influence on the value of surface roughness. 2) The value of MRR is decreases when the tool diameter, spindle speed and feed rate are decreases. 3) For the accuracy of the holes drills, as drill diameter, feedrate and spindle speed increase the dimensional accuracy of drilled hole will decrease[1]

M.M. Okasha, P.T. Mativenga, N. Driver, L. Li (2010) This paper presents the feasibility and basic characteristics of a new approach for micro-drilling In718 alloy sheets at an acute angle, using sequential laser and mechanical drilling Experiment analysis. Sequential laser and mechanical drilling of laser-blind holes JungSoo Nam, Pil-Ho Lee, Sang Won Lee (2011) the experimental characterization of the micro-drilling process with the nanofluid minimum quantity lubrication (MQL) Experimental analysis. The experimental results show that the nano fluid MQL significantly increases the number of drilled holes and reduces the drilling torques and thrust forces. In addition, the nano fluid MQL effectively eliminates remaining chips and burrs to enhance the quality of drilled holes.[19]

B.K Hinds, G.M Treanor (2011) Analysis of stresses in micro-drills. The finite element method Three-dimensional models of drills are defined by setting node points of the drill geometry. Measured forces from experimental tests are used to determine drill loading.[5]

Hongyan Shi, Fumin Song, Lianyu Fu (2011). To present a system for accurately measuring drilling force in the printed circuit board micro drilling process and to characterize the drilling force to provide a better understanding of the micro drilling process. Experimental analysis paper presents a system for accurately measuring the drilling force. Drilling force provides fundamental information for the optimal design of micro drill bits. Drilling force can also characterize the micro drilling process, especially the ultra small hole micro drilling process.[9]

Dr. K.K.Gupta, Prof.Tapan Jain, Manish Deshmukh (2013)Conventional micro Conventional micro-drilling processes in order to find the best quality of drilling for different types of work piece material, experiment is carried out using calculation drill bit diameter, feed and RPM is increases the MRR is also increase.[14]

Rajyalakshmi.G, VenkataRamaiah. P (2013) This paper discusses the application of the Taguchi method with fuzzy logic to optimize the machining parameters for Wire electrical discharge machining with multiple characteristics.[21]

III. Material Removal Rate

The material removal rate (MRR) in drilling is the volume of material removed by the drill per unit time. For a drill with a diameter D , the cross-sectional area of the drilled hole is $\pi D^2/4$. The velocity of the drill perpendicular to the work piece f is the product of the feed and the rotational speed N where $N = V/\pi D$. Thus, $MRR = (\pi D^2 / 4) (f)$ mm³ /min. Conversion of feed rate f_r (mm/rev) to feed rate f (mm/min) $f = N f_r$ (mm/min). Material removal rate is commonly considered as a major manufacturing goal in machining operations in many of the existing research. Taguchi method, an experiment design method, has been widely applied to many industries. It cannot only optimize quality characteristics through the setting of design parameters, but also reduce the sensitivity of the system performance to sources of variation. To achieve the deduction in optimization, it is necessary to first describe the dynamic behavior of the system to be controlled. Because of the number, complexity and unclear, vague nature of the variables of the dynamic systems that may influence the decision maker's decision, fuzzy set theory is the most suitable solution. Fuzzy linguistic models permit the translation of verbal expressions into numerical ones. Therefore, the input output relationship of the process can be described by the collection of fuzzy control rules involving linguistic variables rather than a complicated dynamic mathematical model.[29]

J.Pradeep Kumar, P.Packiaraj (2012) To investigate the effects of drilling parameters such as cutting speed (5,6.5, 8 m/min), feed (0.15, 0.20, 0.25mm/rev) and drill tool diameter (10, 12, 15mm) on surface roughness, tool wear by weight, material removal rate using HSS spiral drill. Taguchi method on Oil hardened/Non Shrinking (OHNS) steel. The feed and speed are used to control surface roughness, tool wear, material removal rate KamalHassana, Anish Kumar, M.P.Garg, (2012) Investigates the effects of process parameters on Material Removal Rate (MRR) in turning. Taguchi method and analysis of variance (ANOVA)/Brass The design of experiment and analysis to study effect of cutting speed and feed on MRR. drilling machine with H.S.S drill bit. Taguchi method on EN8 (harden mild steel) taken as work-piece material. The optimum settings of feed rate and spindle speed so that the thrust force, torque, local circularity error, and machining time can be minimized.[12]

Dr. K.K.Gupta, Prof. Tapan Jain, Manish Deshmukh (2013) Conventional micro Conventional microdrilling processes in order to find the best quality of drilling for different types of work piece material Experimental analysis The experiment using calculation drill bit diameter, feed and RPM is increases the MRR is also increase. drilling processes in order to find the best quality of drilling for different types of work piece material

Experimental analysis The experiment using calculation drill bit diameter, feed and RPM is increases the MRR is also increase.[14].

IV. Taguchi Method

The Taguchi method is a robust design method technique, which will provides a simple way to design an efficient and effective experiment. In order to efficiently reduce the conventional experimental tasks, the orthogonal array by using design parameters will be proposed and adopted. The performance measure, signal-to-noise ratio(S/N) can be used to obtain the optimal parameter combinations. In the Taguchi method, a loss function will be defined to calculate the deviation between the experimental value and the desired value. Usually, there are three categories of the performance characteristics in the analysis of the signal-to- noise ratio, i.e., the lower the-better, the higher the- better, and the nominal-the better .To obtain optimal machining performance, the minimum SR and the maximum MRR are desired. Therefore, the lower the-better SR and the higher-the better MRR should be selected. This method, the S/N ratio is used to determine the deviation of the performance characteristic from the desired value. [22]

Orthogonal array is a testing a black box testing technique which is a systematic, statistical way of software testing It is used when the number of inputs to the system is relatively small, but too large to allow for exhaustive testing of every possible input to the systems. It is particularly effective in finding errors associated with faulty logic within computer software systems. Orthogonal arrays can be applied in user interface testing, system testing, regression testing, configuration testing and performance testing. The permutations of factor levels comprising a single treatment are so chosen that their responses are uncorrelated & hence each treatment gives unique piece of information. The net effect of organizing the experiment in such treatments is that the same piece of information is gathered in the minimum number of experiments.[24]

Hari Singh ,Pradeep Kumar (2004),(2006),(2008) To obtain an optimal setting of turning process parameters – cutting speed, feed and depth of cut, which may result in optimizing tool wear Taguchi's Design of experiments/En24 steel Optimizing Tool wear ,feed force and tool life of Carbide Inserts for Turned Parts by setting of process parameters.[25]

Dong-Woo Kim¹, Myeong-Woo Cho , Tae-Il Seo and Eung-Sug Lee (2008) Application of Design of experiment Method for Thrust Force Minimization in Step-feed Micro Drilling.DOE (Design of Experiment), ANOVA (Analysis of Variance). In this study, only the drilling thrust is taken into account as the most significant factor in order to optimize the step-feed micro drilling processes.[7]

Ashish Bharti, S.K.Moulick (2013) To find the optimized multi response factors for micro drilling operation .Drilling operation is influenced by spindle speed, feed rate, tool point angle, presence of coolant & lubricating agent ,vibration ,tool material ,clearance and chip length. In this case study the Machining parameters spindle speed ,feed rate and tool point is analyzed for their effect on the hole diameter produced and the material removal rate Taguchi based method along with ANOVA (Analysis of Variance) and DOE (Design of Experiments) Output found as spindle speed and feed rate increases material removal rate increases along with nominal diameter but tool point angle has not significant effect and remains constant in this process.[2]

V. Fuzzy Logic

Fuzzy sets are sets whose elements have degrees of membership. Fuzzy sets were introduced by Lotfi A. Zadeh and Dieter Klaua in 1965 as an extension of the classical notion of set. At the same time, defined a more general kind of structures called L-relations, which were studied by him in an abstract algebraic context. Fuzzy relations, which are used now in different areas, such as linguistics decision-making (Kuzmin, 1982) and clustering, are special cases of L-relations when L is the unit interval [0, 1].

In classical set theory, the membership of elements in a set is assessed in binary terms according to a bivalent condition — an element either belongs or does not belong to the set. By contrast, fuzzy set theory permits the gradual assessment of the membership of elements in a set; this is described with the aid of a membership function valued in the real unit interval [0, 1]. Fuzzy sets generalize classical sets, since the indicator functions of classical sets are special cases of the membership functions of fuzzy sets, if the latter only take values 0 or 1. In fuzzy set theory, classical bivalent sets are usually called crisp sets. The fuzzy set theory can be used in a wide range of domains in which information is incomplete or imprecise, such as bioinformatics. [15]

It has been suggested by Thayer Watkins that Zadeh's ethnicity is an example of a fuzzy set. A fuzzy set is a pair where S is a set and μ_S is a function from S to $[0, 1]$. For each $x \in S$, the value $\mu_S(x)$ is called the grade of membership of x in S . For a finite set S , the fuzzy set is often denoted by $\{\mu_S(x) / x \in S\}$. Let $x \in S$. Then x is called not included in the fuzzy set S if $\mu_S(x) = 0$, x is called fully included if $\mu_S(x) = 1$, and x is called a fuzzy member if $0 < \mu_S(x) < 1$. The set $\{x \in S \mid \mu_S(x) > 0\}$ is called the support of S and the set $\{x \in S \mid \mu_S(x) = 1\}$ is called its kernel. The function μ_S is called the membership function of the fuzzy set S . Sometimes, more general variants of the notion of fuzzy set are used, with membership functions taking values in a (fixed or variable) algebra or structure A of a given kind; usually it is required that A be at least a poset or lattice. These are usually called L-fuzzy sets, to distinguish them from those valued over the unit interval. The usual membership functions with values in $[0, 1]$ are then called $[0, 1]$ -valued membership functions. These kinds of generalizations were first considered in 1967 by Joseph Goguen, who was a student of Zadeh.[16]

Tian-SyungLan (2011) In this study, four parameters (cutting depth, feed rate, speed, tool nose runoff) with three levels (low, medium, high) were considered to optimize the surface roughness. Taguchi, orthogonal array, and fuzzy rules The parametric deduction scheme was proposed and applied to achieve the optimum CNC finish turning parameters under the considerations of SR. A confirmation experiment of the optimum deduction parameters was calculated to indicate the effectiveness of the proposed fuzzy deduction optimization method. Through the confirmation test, the experimental results validate the potency that the SR can be advanced from our parametric deduction optimization technique.[26]

Om PrakashVerma, Himanshu Gupta (2012) The work presents in this paper water bath temperature control system which is most widely used process in the process industry. Water bath Fuzzy logic Fuzzy Logic Controller (FLC) based non-linear control for water bath temperature to obtain the desired output water temperature of water bath and to implement them in a real world environment.[20]

Rajyalakshmi.G, Venkata Ramaiah. P (2013) This paper discusses the application of the Taguchi method with fuzzy logic to optimize the machining parameters for Wire electrical discharge machining of Inconel 825 with multiple characteristics. A multi-response performance index (MRPI) was used for optimization. The machining parameters viz., pulse on time, pulse off time, corner servo voltage, flushing pressure, wire feed, wire tension, spark gap voltage, servo feed were optimized with consideration of multiple performance characteristics Taguchi, orthogonal array, and fuzzy rules The Taguchi method with fuzzy logic technique using MRPI converts the multiple performance characteristics into single performance characteristics and, therefore, simplifies the optimization procedure.[21]

Fuzzy rules may be expressed in terms such as "If the room gets hotter, spin the fan blades faster" where the temperature of the room and speed of the fan's blades are both imprecisely (fuzzily) defined quantities, and "hotter" and "faster" are both fuzzy terms. Fuzzy logic, with fuzzy rules, has the potential to add human-like subjective reasoning capabilities to machine intelligences, which are usually based on bivalent boolean logic. [Wang, 1993][28] provides an excellent introduction to fuzzy logic and how it can be applied to AI, and [Kosko, 1993] is an excellent popular science book describing all aspects of fuzzy logic. LOTFI A. ZADEH (1965) Introducing of Fuzzy sets Mathematical Information and Control. (1973) New Approach to the Analysis of Complex Systems and Decision Processes Fuzzy logic .The approach provides an approximate and effective means of describing the behavior of complex system.

For the most part, the fuzzy rules that are used in control systems are hand-crafted by the designers of the systems, and machine learning is rarely employed. As such, it can be argued that this human input into the system's design constitutes a homunculus, and that such systems can never be independently intelligent.

This research work aimed to exploit this in order to investigate the effectiveness of machine learning algorithms when compared to human learning processes. The fuzzy rules will serve well as they provide an excellent means of compactly representing what the human has learned in a way that is both accurately human-like and subjective, and can be used in controlled experiments to be compared against standard machine learning algorithms.[21]

VI. Conclusion

This type of optimization is a difficult method .As this work not only optimization using orthogonal array, but will also be the satisfactory fuzzy technique for improving material removal rate in Micro drilling. The competition of manufacturing industry will then be economically excited through the proposed development in this paper.

VII. References

- [1] Azlan Abdul Rahman,AzuddinMamat," Effect of Machining Parameters on Hole Quality of Micro Drilling for Brass"Vol 3 no.5 pp.221-230.
- [2]. AshishBharti,S.K.Moulick ,(2013)," Parametric optimization of multi response factors in micro drilling operation ", International Journal of Scientific & Engineering Research, Volume 4, Issue 7 pp-1157-1163.
- [3] B.Y. Lee, H.S. Liu and Y.S. Tarng, (1996). Modeling and Optimization of Drilling Process. Department of Mechanical ManufactureEngineering, National Huwei Institute of Technology, Huwei, 632, pp. 1-9.
- [4] B.Y. Lee, H.S. Liu and Y.S. Tarng, (1998). Modeling and optimization of drilling process, Journal of Materials Processing Technology, 74,pp. 149-157
- [5]. B.K Hinds, G.M Treanor ,(2011)" Analysis of stresses in micro-drills using the finite element method" International Journal of Machine Tools and Manufacture.
- [6] C. Lin, S.M. Kang and K.F. Ehmann, (1992). Planar Micro-Drill Point Design and Grinding Methods, Transactions of the North AmericanManufacturing Research Institution of SME, pp. 173-179.
- [7]. Dong-Woo Kim1, Myeong-Woo Cho , Tae-Il Seo and Eung-Sug Lee (2008)." Application of Design of Experiment Method for Thrust ForceMinimization in Step-feed Micro Drill" Sensors, 8,pp. 211-221
- [8] F.H. Jung and D.L Psang, (2002). Mathematical model of multiflute drill point, International Journal of Machine Tools & Manufacture, 42,pp. 1181-1193.
- [9]. Hongyan Shi, Fumin Song, Lianyu Fu, ,(2011)" Experimental study on drilling force in printed circuit board micro drilling proces" Circuit World (impact factor: 0.44). 02/2011; 37(1):24-29. DOI:10.1108/03056121111101250
- [10] J. Zhang, and A. Knoll, "Designing Fuzzy Controllers by Rapid Learning," FuzzySets and Systems, 101, 287-301, 1999
- [11]. Jung Soo Nam, Pil-Ho Lee,Sang Won Lee,(2011) "Experimental characterization of micro-drilling process using nanofluid minimum quantity lubrication" 10.1016/j.ijmachtools,

- [12] J.Pradeep Kumar, P.Packiaraj,(2012), "EFFECT OF DRILLING PARAMETERS ON SURFACE ROUGHNESS, TOOL WEAR, MATERIAL REMOVAL RATE AND HOLE DIAMETER ERROR IN DRILLING OF OHNS "IJAERS/Vol. I/ Issue III/April-June, 2012pp-150-154
- [13] .Kamal Hassan, Anish Kumar*, M.P.Garg*, (2012) "Experimental investigation of Material removal rate in CNC turning using Taguchi method "International Journal of Engineering Research and Applications Vol. 2, Issue 2pp.1581-1590.
- [14]. K.K.Gupta,Prof. TapanJain,ManishDeshmukh ,(2013) ,"Optimization of Process Parameters in HighRPM Micro Drilling Machine"JIET,Vol 2,pp-128-130.
- [15] L.A. Zadeh, "Fuzzy Sets," Information and Control, 8, 338-352, 1965
- [16] L. A. Zadeh, "Outline of a New Approach to the Analysis of Complex Systems and Decision Processes," IEEE Transactions on Systems, Man, and Cybernetics, SMC- 3(1), 28-44, January 1973.
- [17]. Lan T.-S., Lo C. Y., Wang M.-Y. and Yen A-Y, (2008), "Multi Quality PredictionModel of CNC Turning Using Back Propagation Network", Information
- [18] M. Black, "Vagueness: An Exercise in Logical Analysis," Philosophy of Science, 4,427-455, 1937
- [19]. M.M. Okasha, P.T. Mativenga, N. Tian-SyungLan(2010), Parametric Deduction Optimization for Surface Roughness, American Journal of Applied Sciences 7 pp-1248-1253
- [20]. Om PrakashVerma, Himanshu Gupta, (2012) Fuzzy Logic Based Water Bath Temperature Control System . International Journal of Advanced Research in Computer Science and software Engineering Volume 2, Issue 4, pp-333-336.Driver, L. Li (2010), Sequential laser and mechanical micro-drilling of Ni superalloy for aerospace application , CIRP Annals - Manufacturing Technology,pp-199-202,00.
- [21]. Rajyalakshmi.G, VenkataRamaiah.P ,(2013)," Optimization of Process Parameters of Wire Electrical Discharge achiningUsing Fuzzy logic Integrated with Taguchi Method" International Journal of Scientific Engineering ndTechnology (ISSN : 2277-1581)Volume No.2, Issue No.6, pp : 600-606
- [22]. Sahoo P., Barman T. K. and Routara B. C., (2008), "Taguchi based practicaldimension modeling and optimization in CNC turning", Advance in ProductionEngineering and Management, Volume 3, Number 4, pp. 205-217.
- [23] Singh H. and Kumar P., (2006), "Optimizing Feed Force for Turned Parts throughthe Taguchi Technique", Sadhana, Volume 31, Number 6, pp. 671-681.
- [24]. Singh H. and Kumar P., (2004), "Tool wear optimization in turning operation by Taguchi method",Indian Journal of Engineering & Material Sciences Volume 11, pp. 19-24.
- [25]. Singh H. (2008), "Optimizing Tool life of Carbide Inserts for Turned Parts using Taguchi Technique", Volume II , International MultiConference of Engineers and Computer scientists pp.978-988.
- [26] . Tian-SyungLan,(2011). Fuzzy Parametric Deduction for Material Removal Rate Optimization, Journal of Mathematics and Statistics,7(1), pp.51-56
- [27]. "The future is fuzzy," Newsweek, May 1990
- [28]. Thamizhmanii S., Saparudin S. and Hasan S., (2007), "Analysis of SurfaceRoughness by Using Taguchi Method", Achievements in Materials and Manufacturing Engineering, Volume 20, Issue 1-2, pp. 503-505.
- [29] Tian-SyungLan,(2011). Fuzzy Parametric Deduction for Material Removal Rate Optimization, Journal of Mathematics and Statistics,7(1), pp.51-56
- [30] THIREN G. POKAR ,PROF. V. D. PATEL,(2013) "Optimization and Modeling of Micro drilling Process Parameters" International Journal of Research in Modern Engineering and EmergingTechnologyVol. 1, Issue: 2, pp 26-30.

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