A State of the art on Sequential Micro-Machining

R M Tayade*, B Doloi, B R Sarkar and B Bhattacharyya
Production Engineering Dept., Jadavpur University, Kolkata, India
*rtayade@vjti.org.in

Abstract. The sequential micro-machining (SMM) is an emerging technique highly recommended for the manufacture of micro parts and also for generating micro features on parts. The review incorporates various traditional as well as non-traditional machining processes used in sequential manner. This paper focuses on recent trends in sequential micro machining combining diverse machining processes such as electrical discharge machining (EDM), laser beam machining (LBM), electrochemical machining (ECM), ultrasonic machining (USM), electrochemical discharge machining (ECDM), micro milling, micro grinding, electro-polishing, etc. The basic concepts, working principle, classification, mechanism of operation, the rationale behind the sequencing of individual machining processes etc. are described elaborately.

1. Introduction

In order to fulfill the difficult to meet requirements of tighter tolerances imposed on the parts to be produced, manufacturing industries are searching for different innovative methods and processes for the manufacture of micro-parts. Sequential machining being a promising futuristic technology; it is considered to be an important link in the chain of innovative and advanced micro-part manufacturing methods. The sequencing technique aims at machining in the same set up instead of relocating the workpiece in different machine tools for carrying out further operations on it. The multifunctional machine tool executing dissimilar machining processes in a sequential manner reduces effort, energy and machining time to a great extent. In spite of the several complimentary advantages, very few non-conventional machining processes are integrated for forming sequential machining combination. This methodology imparts a much higher level of accuracy to the micro-part and also improves the machining efficiency.

Basically, sequential machining is a plan of action where two or more machining processes are executed in sequence on the same or different machine tools. The strategy of implementation of different machining processes in a sequential manner, on the one hand, extracts the advantages from the individual process and minimizes the disadvantages. The trend of incorporating two or more micromachining systems at one workstation for performing various machining operations in a sequential manner has been increasing. It is well known that each and every discreet machining process has its own pros and cons. The µEDM cuts metal very fast but induces thermal stresses in the component, µECM offers stress-free machining but it is difficult to achieve perfect profile due to uncontrolled anodic dissolution. Frequent changing and setting of micro-tool is also a problematic area of micromachining which can be addressed by manufacturing tool online. Thus the methodology of applying these micro machining techniques in a sequence is adopted and it is termed as Sequential.
Micro Machining (SMM). The sequential machining has the capability to fabricate complex micro features, channels, grooves; micro pyramids, etc on difficult to cut materials. It is more efficient, advantageous, stable, and economically feasible than other manufacturing techniques.

2. Basics of Sequential Micro-Machining

In sequential machining, two or more machining techniques are applied in a sequential manner on the same or different working systems. As all the required operations on the workpiece, right from initial cutting to final finishing are carried out without changing the tool and workpiece positions, the components with high geometric accuracy and better surface finish can be produced with high machining efficiency. The workpiece handling time, loading and unloading time reduces to a great extent. The efforts are being made to incorporate more and more machining processes in a single multifunctional machine system to avoid repositioning error and to achieve cost-effective manufacturing. The sequential micro-machining can be broadly classified into two major groups such as conventional sequential machining processes and non-conventional sequential machining processes. Figure 1 represents the broader classification of Sequential micro-machining processes. The sequential machining processes are classified under five major heads based on the purpose of operation as; i).micro-tool making oriented processes like Turning and EDM, ii). Based on the increase in material removal rate, the machining combinations include; ECM and EDM, LBM and EDM, etc. iii).The processes enhancing surface quality such as EDM and ECM milling and EDM with electro-polishing, iv). The energy-efficient processes and v).The processes improving the microstructure such as surface defect machining (SDM) [1]. Most of the time the sequential machining and hybrid machining are considered as one and the same, but actually, both the machining techniques are totally different from each other. In hybrid machining, two or more micromachining processes occur simultaneously at one station. Hybrid manufacturing is defined as the simultaneous and controlled interaction of process mechanisms and/or energy sources or tools that have a significant effect on the process performance. Generally assisted or combined machining processes come under this category. For example, laser-assisted turning; where the workpiece materials which are hard are preheated and soften by the focused stream of the laser beam before it reaches to the tip of the cutting tool. In the case of sequential machining, the subsequent machining process is applied after the completion of the first process.

3. Development of sequential micro machining systems
The intention behind writing the review was to bring the area of sequential machining into the limelight by understanding the methodology of application, a strategy of sequencing, to focus on developing sequential machining processes and to highlight the most popular sequential machining combinations. The various non-traditional micromachining processes applied in a sequential manner are described elaborately.

3.1. Sequencing Laser Beam Machining (LBM) and μEDM
A nanosecond pulsed laser was used for micro hole drilling, as drilling by using μEDM is a time-consuming process and wear of tool during machining also takes place [2]. Therefore, initially, the pilot hole of 1mm depth was drilled by focusing a laser beam on the workpiece material. The LBM and the μEDM combination were used as shown in figure 2 for drilling holes in fuel injector [3]. Firstly the pilot holes in the injection nozzle of the Diesel engine were drilled by using laser ablation. The removal of the recast layer and finishing of the hole by reaming operation was conducted by μEDM drilling. This sequential machining allows 70% reduction in total drilling time in conventional EDM. The sequential combination of die sinking EDM and LBM was used for inscribing gear wheel in hardened steel [4]. Initially, the major portion of the gear i.e. gear blank was machined by using Die sinking EDM. The important gear tooth profile in detail then carved by using Nd: YAG laser.

3.2. Sequencing of LBM and micro Milling
The hot embossing dies used for micro-fluidic application were produced by implementing LBM process in sequential combination with micro-milling [5]. Both the machining processes were carried out on separate machining setups. Initially, the micro-fluidic channels were structured by using a laser ablation process. As such dies cannot be manufactured either by micro milling or simply by using LBM. The strategy of sequencing LBM and micro milling offers the advantages of an individual machining process.

3.3. Sequencing of Block μEDM and μEDM
This sequencing technique is generally implemented for the production of high aspect ratio microelectrodes with higher dimensional accuracy. The multifunctional machine tool used for manufacturing micro tool of difficult to cut metal. In Block μEDM process, a rectangular sacrificial block of tungsten carbide (WC) acts as a cutting tool. The cylindrical rod which is required to be reduced to a tool electrode acts as a workpiece. The electrode rod having a rotary motion is fed against the block surface during machining as shown in figure 3. The sacrificial block or the tool electrode is imparted to and fro scanning movement to avoid taper on the tool electrode. This process permits to fabricate tool electrodes of less than 40μm diameters [6].
3.4. Sequencing of µEDM and micro grinding processes

Polycrystalline diamond (PCD) is considered as one of the hardest and toughest materials often used for cutting difficult to machine metals. The effect of the PCD tool on the glass during micro grinding has been investigated. The PCD micro tool was first made online by applying block µEDM as well as moving block µEDM process. The same PCD tool was then used for micro grinding the glass. Both the machining processes; block µEDM micro tool making and glass grinding were performed in the same setup without changing the working fluid [7]. Thus the fine finished micro tool imparts high surface quality and enhances dimensional accuracy of the hole.

3.5. Application of µECDM and µECM in sequential manner

A novel combination of micro ECDM (µECDM) shaping and µECM finishing process in a sequential manner for micro hole drilling have been presented [8]. Initially using µECDM process, a hole was drilled on 500µm thick SS-304 stainless steel plate. The hole formed by µECDM process consists of the recast layer which was removed by subsequent application of the µECM process. Figure 4 (a) shows a hole drilled using the µECDM process and finished by a µECM process as shown in figure 4(b).

3.6. Sequential combination of block µEDM, µEDM and µECM

Three micromachining processes such as block µEDM, µEDM and µECM conducted in sequence on the same machining system without changing the tool and workpiece positions [9]. First of all, a tool...
diameter was reduced by Block Electric Discharge Grinding (BEDG) method. The micro-hole then drilled with the same tool electrode using µEDM process. The micro-cracks, micro-craters generated on the hole surface then finished by applying µECM process.

3.7. Sequential combination of µECM and µEDM

A prototype machine tool was designed and developed to conduct µEDM and µECM processes sequentially to investigate the effects of the application of µECM sinking and µEDM sinking for making star-shaped cavity [10]. The applied sequential machining strategy showed a double decrease in the machining time required for milling a cavity in comparison with the µEDM process.

3.8. Sequential combination of µEDM and µUSM

A sequential combination of µEDM tool shaping and micro ultrasonic machining (µUSM) for hole drilling on borosilicate glass was presented. Initially, tool diameter reduced to 150µm by using µEDM process. The ultrasonic vibrations of 30 kHz frequency transmitted to borosilicate glass. The same micro tool then used to drill high aspect ratio micro hole in borosilicate glass [11].

4. Conclusions

The review enumerated in this paper has tried to encompass various sequential combinations of different micromachining processes. A broader classification of sequential micromachining processes has been presented by taking into account a wide scope of conventional and non-conventional machining domain. The integrated multipurpose system set up of sequential micro machining is the current trend to accommodate various machining processes such as EDM, LBM, ECDM, USM, ECM, BEDG etc. to overcome the problems of an individual process. The sequential machining strategy offers various advantages such as improved surface quality, high dimensional accuracy and enhanced machining efficiency. The sequential micromachining is in rudimentary form, as very few sequential machining combinations are developed yet. The system set up accommodating EDM, ECM and ECDM can be developed. The SMM can be combined with hybrid machining processes.

References

[1] Chavoshi S Z, Goel S and Morantz P 2017 Current trends and future of sequential micro-machining processes on a single machine tool Materials & Design vol 127 pp 37-53
[2] Kim S 2009 Hybrid micromachining using a nanosecond pulsed laser and micro EDM J. Micromech. Microeng. vol 20 (1) 015037
[3] Li L, Diver C and Atkinson J 2006 Sequential Laser and EDM Micro-drilling for Next Generation fuel Injection Nozzle Manufacture CIRP, Annals vol 55 (1) pp 179-182
[4] Fleischer J, Schmidt S and Haupts S Combination of electric discharge machining and laser ablation in microstructuring of hardened steel 2006 Microsyst Technol. vol 12 pp 697–701
[5] Schubert A, Goerl S, Schulz B and Eckert U 2011 Sequential combination of micro-milling and laser structuring for manufacturing of complex micro-fluidic structures Physica Procedia vol 12 pp 221–229
[6] Jahan M P, Rahman M, Wong Y S and Fuhua L 2010 On-machine fabrication of high-aspect-ratio micro-electrodes and application in vibration-assisted micro-electrodischarge Proc. Inst. Mech. Eng. B J. Eng. Manuf. vol 224 (5) pp 795–814
[7] Perveen A, Jahan M P, Rahman M and Wong Y S 2012 A study on micro grinding of brittle and difficult-to-cut glasses using on-machine fabricated poly crystalline diamond tool
[8] Tayade R M, Doloi B, Sarkar B R and Bhattacharyya B 2017 Study of Sequential Electro Micro Machining (SEMM) System for Enhancing Machining Performances Int. Conf.(COPEN, IIT Madras) ISBN 978-93-80689-28-9 pp 120-124
[9] Xiaolong H, Yukui W, Zhenlong W and Zhaoqi Z 2013 Micro-hole drilled by EDM-ECM combined processing Key Engineering Materials Online ISSN: 1662-9795 Vol 562-565 pp 52-56

[10] Skoczypiec S and Ruszaj A 2014 A sequential electrochemical electro-discharge process for micropart manufacturing Precision Engineering vol 38 pp 680-690

[11] Yan B H, Wang A C, Huang C Y and Huang F Y 2002 Study of precision micro holes borosilicate glass using micro EDM combined with micro ultrasonic vibration machining International Journal of Machine Tools & manufacture vol 42 pp 1105–1112