Study of Sequential Electro Micro Machining (SEMM) System for Enhancing Machining Performance

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Abstract

Sequential Electro Micro Machining (SEMM) is a combination of different electro-micromachining processes such as Electrochemical micromachining (µECM), Electro-discharge micromachining (µEDM) and Electro-chemical discharge micromachining (µECDM) which are applied in a proper sequence on a single machine tool. SEMM utilizes the advantages of the individual processes to enhance the machining rate, dimensional accuracy, reduced tool wear rate and surface roughness. Through this paper an attempt has been made to explain the fundamentals of SEMM process highlighting the various electro- micromachining processes involved in it. This paper discusses about various elements of developed SEMM system which includes power supply unit, mechanical machining unit of tool feeding and workpiece holding, electrolyte or dielectric fluid flow circulation unit etc. The paper also includes some experimental results of micro drilling on stainless steel (SS304) by utilizing developed SEMM setup as per planned sequence of µECDM and µECM processes.

Keywords: (SEMM), electrochemical micromachining (µECM), Electro-discharge micromachining (µEDM), Electro-chemical discharge micromachining (µECDM).

1. INTRODUCTION

In today's scenario of ultra-precise, advanced equipments, manufacturing industries have no option but to opt for an automation and miniaturization to produce sophisticated products. In each and every sector of manufacturing, advanced materials &highly automated systems are being used. Scientists & researchers are striving hard for exploring innovative and effective micro-part manufacturing techniques. As a response to these necessities, advanced machining processes are emerging. These non-conventional machining processes offer several inherent advantages that includes achievement of close dimensional tolerances on metal parts, high metal removal rate, ultra high surface finish and it also encompasses machining of almost all types of conducting, non-conducting, semiconducting materials. These unique but diversified processes includes Abrasive Jet machining (AJM), Laser Beam Machining (LBM), Ultrasonic machining (USM), Electrochemical Machining (ECM), Electro-Discharge machining (EDM) etc. These processes have their own pros and cons as thermal processes such as EDM, LBM & EBM may lead to the thermal distortion of the parts to be machined. Chemical machining or Electrochemical Machining cannot be used for machining of non-conductive materials where as ECDM i.e. Electrochemical Discharge machining can be employed to machine conductive as well as non-conductive materials. So each and every individual process has its own advantages and disadvantages. In order to find the way out of this situation and to utilize the potential of these techniques, sequential machining is the new approach. It is one of the most appealing and promising technology in the area of micro-part manufacturing where two or more individual micromachining techniques are applied in a sequence on a single or different machine tools. This technique can be employed on a multifunctional machine tool as well. Sequential machining is the newest concept and very less work is reported in this area. Reviews on various research activities carried out in the field of sequential machining in the past as well as the basic micro-machining processes involved in SEMM is presented herewith. B. Bhattacharyya et.al. [1]. studied the influence of various EMM parameters on material removal rate (MRR), surface finish and accuracy of the micro-part and came up with valuable suggestions such as larger side gap formation surrounding the electrode is due to the increased voltage and frequency which leads to the increased bursting of hydrogen gas bubbles it enhances the micro-sparking in the narrow inter-electrode gap (IEG) which removes the metal exorbitantly surrounding the electrode, forming wider side gap. Sebastian S. et. al. [2]. designed and developed machine tool at Production Engineering Dept., Cracow University of Technology, Poland. to investigate the effects of application of electrochemical and electro-discharge micro-machining in sequence for the manufacture of 3-D sculptured surface with high dimensional accuracy and surface finish. Zhaoqi Zeng et al.[3]investigated the combined µEDM and µECM for milling 3-D micro-structures on the same machine tool and with the same tool electrode. They applied µEDM for roughing and µECM for finishing by controlling the important process parameters such as optimal machining voltage 10V, initial machining gap 10µm, and tool feed rate 10µm/s during µECM. Li Xiaowei et al.[4] adopted combined electrical discharge machining (EDM) with orbital motion of work piece and stationary pulse electro-chemical machining (PECM) for the production of flexure hinge. Here, along with µEDM, µECM with microsecond –scale pulsed current is used. Due to application of microsecond scale pulsed electro-chemical machining (MPECM), more localization of anodic dissolution took place. T Kurita et al [5] developed table top size prototype of hybrid micro-machine tool with five changeable machining unit. This system is capable to perform mechanical machining, non-conventional machining, and complex machining on single machine tool. The complex operation performed sequentially are electrode machining by milling, hole shaping by EDM and hole finishing by ECM. S.Skoczypiec et al.[6] presented the conception of electrochemical (EC) and µEDM processes combination into single sequential machining method. Modeling of 3D-EC and 3D-ED sequential micro-machining technology based on the mathematical model in order to design and optimize the machining sequence process planning. Z. Qinjian et al. [7] performed machining on polycrystalline diamond (PCD). They applied Electrical discharge machining process in combination with ultrasonic assisted mechanical

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machining. Here the material from the PCD workpiece to which ultrasonic vibrations provided is removed due to spark discharge action and rate of machining is enhanced by mechanical cutting action performed by diamond grit present on bronze bonded diamond wheel. [8] B. Doloi et al. executed hole drilling operations on non-conducting zirconium oxide ceramic material and concluded that the three most influential parameters namely applied voltage, electrolyte concentration and interelectrode gap significantly affect the MRR as well as ROC while performing µECDM.

2. MACHINING METHODS INVOLVED IN SEQUENTIAL ELECTRO MICRO- MACHINING (SEMM)

2.1 Electrochemical micro- machining (ECMM / µECM)

In µECM, electrical energy is used to produce chemical reaction in the electrolytic cell consisting of two electrodes immersed in an electrolyte solution. Low voltage of the order of 1 to 10 volts with ultra-short DC pulsed current is applied between the pre- shaped micro-tool i.e. cathode and metallic workpiece i.e. anode. Both the electrodes are separated by a narrow inter electrode gap (IEG). During electrolysis, removal of material from the surface of workpiece takes place due to electrochemical dissolution. This anodic dissolution results in the formation of approximate mirror image of micro-tool on the workpiece. The rate of anodic dissolution is governed by Faraday's laws of electrolysis. During electrochemical dissolution, the material from anode surface is removed atom by atom and workpiece experiences stress free machining. No thermal stresses induced, no burr formation and high quality surface finish is obtained on the surface of micro-part without affecting the tool life. In µECM, an electrolyte used completes the circuit and allows electrolysis process to occur. Generally acidic, basic and neutral aqueous solutions are used as electrolytes. An aqueous solution of sodium chloride or sodium nitrate is the most commonly used electrolytes.

2.2 Electrodischarge micro- machining (EDMM/ µEDM)

Electro-Discharge Micro-Machining (µEDM) has a capability of machining intricate micro-features with high dimensional accuracy in hard and difficult-to- cut materials. It is based on thermoelectric energy generated between the tool electrode and the work piece, Hence material removal mainly depends on thermal properties rather than mechanical properties of work metal. Both the electrodes are placed in the dielectric medium apart from each other maintaining specific IEG generally in the range of 5 to 50µm. Depending upon the applied potential difference and the gap between the tool and workpiece, an electric field would be established. The removal of unwanted material from the surface of the parent metal takes place due to the melting and vaporization of electrode materials because of the repetitive spark discharges. The electrode and the work piece both needs to be electrically conductive in order to generate sparks. EDMM being a thermal process, It imparts certain flaws such as formation recast layer, heat affected zone, micro cracks etc. in the machined part. During machining, used should provide an oxygen free environment along with assisting spark generation. To assure good flow characteristic and efficient cleaning of eroded particles from IEG, dielectric should have low viscosity and low specific gravity. EDM oil/hydrocarbon oil, transformer oil, paraffin, kerosene, deionized water are used as dielectric.

2.3 Electrochemical discharge micro- machining (ECDMM/ µECDM)

µECDM is a hybrid non-nontraditional machining process, used to machine various micro features like holes, micro channels, microgrooves and 3-D intricate shapes on electrically conductive as well as non-conductive materials. In this, the tool & auxiliary electrode are placed about 10 to 50 mm. apart in electrolyte solution like NaOH, KOH or NaCl etc. and are connected to DC power source. The material to be machined is kept in the vicinity of tool electrode. Due to application of potential difference across the electrodes, hydrogen and oxygen gas bubbles generated at tool and auxiliary electrode respectively. When the voltage supplied is beyond the critical value, hydrogen gas bubbles coalesce into a thin film surrounding the tool electrode this film acts as an insulator which almost stops the current. This situation results in development of high electric field (about 10V/µm.) across thin film which produces spark discharge. Hence chemical etching and electro-discharge action results in removal of material from the work surface.

3. FUNDAMENTALS OF SEQUENTIAL ELECTRO MICRO- MACHINING (SEMM)

To satisfy the increasing demands of high dimensional accuracy, better surface quality on the micro-parts, SEMM is found to be a suitable choice. As it is stated earlier that sequential micromachining can be executed if and if more than one machining processes are applied in a sequence on a single or multiple machine tools. A few number of sequential micromachining processes have been developed so far. Saeed Zare Chavoshi et al. [9] for the first time categorically classified these processes into five major categories on the basis of purpose of operations such as micro-tool making, machining time, machining surface quality, energy efficiency and microstructure improvement. The main concern behind application of micromachining technique in a sequence is to minimize the disadvantages and to exploit the advantages of each individual process. Combining µECDM and µECM processes is one of the approach and Combining µEDM and µECM is another approach to achieve high metal removal rate (MRR) and improved surface finish. The capability of the system increases as right from initial machining to final finishing, each and every operation is performed in a single machine tool. It reduces repositioning error, realignment error, reduced workpiece handling time, this results in improves machinability, increased product quality. Reduction in total machining time leads to increased overall machining efficiency. In SEMM, the sequence of operations can be either µEDM first or µECDM then µECM or vice versa. Generally, for removing the white layers formed due to µEDM and to get smooth surface finish, sequence of operation would be µEDM or µECDM first and then µECM, whereas for achieving high metal removal rate µECM would be followed by µEDM or µECDM.

4. DEVELOPMENT OF SEMM SYSTEM

The concept of applying µECM, µEDM or µECDM technologies on a single machine table in a sequence has been proposed. The success of the system depends on contributing, coordinating and assembling the resources, various process equipments based on their functionality.

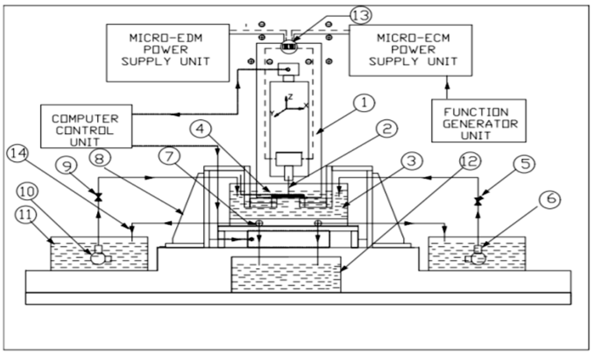

Fig. 1 Schematic diagram of indigineously built SEMM set up.
1). X-Y-Z translation stage, 2). microtool, 3). main machining chamber, 4). Workpiece, 5). Dielectric flow control valve. 6). Dielectric circulating pump with filter, 7). Three way L– port control valve, 8).workpiece mounting stand, 9). Electrolyte flow control valve, 10). electrolyte circulation pump with filter, 11). Electrolyte settling tank, 12). flush tank, 13). T Switch , 14). used electrolyte returning channel.

In order to bring the workable system to existence, many difficulties and challenges have been faced. As except few similarities between both the processes like machining kinematics, system hardware; tool, workpiece etc. combining hardware and software system was a tedious task. In the present research work an effort has been made to design and develop the full-fledged SEMM system which will be less expensive, versatile and economically viable in comparison with prevailing other non-conventional machining methods for the successful adaptability of this system in the various manufacturing industries. The developed SEMM experimental set up consists of power supply units, mechanical machining unit, and fluid flow circulation unit.

Figure No. 2. Photographic view of SEMM system.

4.1 Requirement of Power supply units

Power supply rating of µEDM, µECDM and µECM are different, hence separate power supply units are required. In µEDM or µECDM R-C type pulse generator is used. During machining, to maintain constant polarity, DC power supply is used. In µEDM, or µECDM the voltage required for machining is in the range of 60 to 180 volts and current range is up to 5 Amp. The main input available power supply line has 3-Phase, 440V. AC. The reduction of input voltage and conversion of it from AC to DC have been achieved by applying step down transformer and silicon diode controlled rectifier unit respectively. For measuring and recording of output voltage and current, voltmeter and ammeter are connected at proper place in the circuit. An arrangement is made to protect machine, transformer and rectifier against overload condition and short circuits. For µECM, power supply required may be DC (full wave rectified) or pulsed DC. In present experimentation, pulsed DC power supply is used. The available power supply has voltage in the range 0 to 15V and a current rating of up to 5A. To generate required nature of pulses, pulse generator unit is used. A digital storage oscilloscope (DL 1520 Yokogawa, Japan) is used to know the nature of pulse and to monitor the machining conditions. T switch to enable switching of power alternately for µEDM or µECDM and µECM machining.

4.2 Mechanical machining unit

The mechanical machining unit has been equipped with various functional elements such as tool holding and feeding unit and workpiece mounting unit. A tool holding device fabricated from acrylic material is developed and attached to the Z axis of stage. The XYZ translation stage on which the tool is mounted has a resolution of 0.1 µm. workpiece mounting unit is also fabricated from acrylic material since it possesses resistance to electricity and corrosion, because some portion of this unit will always remain submerged in the corrosive working fluids like dielectric or electrolytes. This material has high strength to withstand the forces coming on structure during loading and unloading the workpiece. There is a provision of holding workpiece rigidly with the help of two small screws and clamps in the housing. Out of these two screws one is connected to the positive terminal of the power supply system through workpiece. Rigid stand is bolted down firmly to the machining table as shown in figure No. 2

4.3 Fluid flow circulation unit

The main machining chamber which contains workpiece is connected to two separate chambers of electrolyte and dielectric through three way L - port valves as shown in Fig.1. to perform µEDM and µECM. The chamber size is kept optimum by considering the maximum size of workpiece to be accommodated and economical and judicious use of working media. In order to maintain circulation of working fluid in the machining zone and to discharge it to the respective electrolyte/dielectric chamber, L port valve is used. During µEDM process, controlled flow of dielectric is maintained with the help of motor pump with filter and flow control valve. For µECDM operation, the electrolyte is used as working medium in which tool is just inserted and auxiliary electrode is dipped into the electrolyte. For µECM operation, the L port valve on electrolyte side is opened so that circulation of electrolyte continues. In this way, this system allows to perform µEDM or µECDM and µECM in a single setup by changing the working media and without changing the tool workpiece position.

5. EXPERIMENTAL PLANNING

From the past research on sequential machining, it is observed that very few researchers have applied µEDM and µECM processes in a sequence .Whereas applying µECDM and µECM processes in a sequence for machining metallic products is not reported till now. As we know µECDM process is generally applied for machining electrically conductive as well as non-conductive materials. We realized that µECDM can be used for machining non-conductive materials very conveniently, whereas applying µECDM for machining conductive metals such as stainless steel is a bit difficult task. As in case of µECDM, electrode tool always remains in contact with (usually non-conducting) workpiece. But while machining metallic components this rule is not followed. Because it is observed that as soon as tool electrode touches the conducting workpiece, system draws more current from the power supply which stops the generation of micro-sparks and welding at the tool electrode and workpiece interface takes place, which stops the further machining process. The workpiece material used for this experimentation is SS-304 grade stainless steel of 500 µm. thickness. To sort out the problem of welding, an arrangement made which maintain particular gap between tool and workpiece and also continues to provide constant tool feed motion. For µECDM, three phase pulsed D.C. power supply with voltage range 0 to 100 V. and current rating up to 5 A. is used. When applied voltage is in the range of 30 to 40 volts, the generated micro-sparks start melting and vaporization of metal from the workpiece surface. For this process, an aqueous solution of sodium hydroxide (NaOH) 10 wt. % is used as an electrolyte. A constant IEG of 50 mm. between the tool and auxiliary electrode is maintained throughout experimentation. After the machining is over, the observations of drilled micro-hole are captured with the help of online monitoring microscope. After µECDM, to ameliorate the surface roughness, µECM process needs to be carried out in a sequence. For this, individual µECM power supply brought in action, auxiliary electrode is removed from machining chamber, constant IEG of 10 µm. is maintained, previously used electrolyte is replaced by 0.1 mole of sulfuric acid (H_2SO_4) solution and positive terminal of power supply is now directly connected to the workpiece. After making these alterations in the system, various parameters such as applied voltage 7Volts, frequency 10 KHz. and duty ratio 40 % is set in µECM power supply unit.

6. EXPERIMENTAL RESULTS AND DISCUSSION

An attempt has been made to find the feasibility of experimentations on newly developed SEMM system by conducting some pilot experiments. In order to drill holes by µECDM process on SS304 grade stainless steel plate, there is a requirement of adjusting gap between the tool electrode and the workpiece. Usually 150µm to 200 µm gap is maintained before initializing machining. If the initial gap distance is smaller than the above mentioned value, voltage drops below 0.5 V and current increases above 1A. It results in the generation of gas bubbles in high density in between tool and workpiece, high heat generated and electrolyte start boiling without generating sparks. Tungsten carbide electrode tool of 250 µm. diameter, provided with reciprocating motion is fed gradually towards the workpiece. The machining takes place in the voltage range of 30V to 35V. The progress of the machining is observed by online monitoring system. Online microscope is used to take the micrographs of drilled blind hole. As the µECDM process is conveniently applied for machining of non-conducting materials, where spark produced by electro-discharge action removes material due to spalling effect. Whereas while machining metallic components, material removal takes place due to melting and vaporization. Partially vaporized metal is responsible for the formation of recast layer. Fig.3 (b) clearly shows the formation of raised portion of the recast layer with some heat affected zone around the periphery of drilled hole surface. In order to improve the surface characteristics and to minimize the recast layer, µECM process is applied at the same location. The setup design makes it possible to perform µECM process without changing the tool workpiece position. Fig. 3 (c) shows hole finished by sequential machining process, where µECM is applied after µECDM process. There is complete removal of recast layer from the micro-hole. The Fig.4 shows surface roughness (Ra) value (0.0472 µm.) of micro-hole measured by CCI- Taylor Hobson, after applying sequential micro-machining process. Fig. 5 (a) and (b) shows drilled micro holes with increased radial overcut, when the applied voltage is 40 volts and 50 volts respectively.

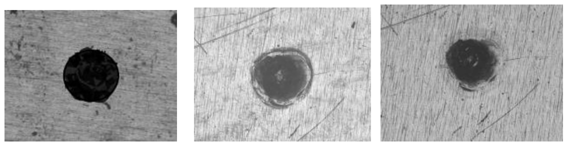

Fig. 3. (a) hole drilled by µECM process. (b) hole drilled by µECDM process, (c) µECDM hole finished by µECM sequentially.

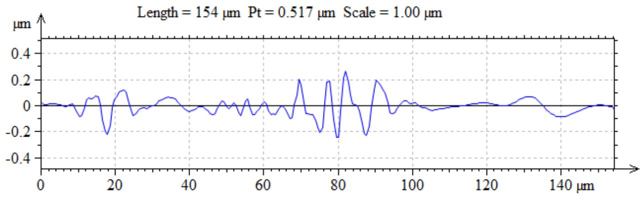

Fig. 4 Surface roughness of micro hole after applying SEMM.

(a) (b)

Fig. 5 Holes drilled when applied voltage is (a) 40 Volts, (b) 50 volts.

7. CONCLUSIONS

Sequential electro-micromachining setup has been designed and developed indigenously. Micro-drilling on stainless steel (SS304) has been performed by applying µECDM and µECM methods sequentially. The hole surface becomes rough around the periphery of micro hole due to formation of recast layer using µECDM process, and then hole surface is finished by µECM process sequentially. The surface roughness Ra value of finished holes surface is obtained as 0.0472 µm. The radial overcut of the hole is varying from 4.215µm to 9.92 µm, when the applied voltage varies from 40 to 50 Volts during µECDM process. By controlling the process parameters of sequential micro-machining, holes with low overcut and better surface finish has been generated. Further experimental analysis is required for optimum control of process parameters for achieving maximum yield criteria utilizing the developed SEMM system.

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