Design and Development of an Electrochemical Spark Micro Manufacturing Equipment

Anjali V. Kulkarni
Centre for Mechatronics, IIT Kanpur, Kanpur, India
Email: anjalik@iitk.ac.in

V. K. Jain
Mechanical Engineering Department, IIT Kanpur, Kanpur, India
Email: vkjain@iitk.ac.in

***Abstract*—To meaningfully meet the intriguing challenges of the product miniaturization, issues must be addressed in the studies of processes useful for microfabrication. The performance of electrochemical based spark process, an advanced machining process used for micromachining has been studied. In order to study the performance of the process, a proper experimental equipment is needed, which should have the precision and accuracy demanded to achieve the micromachining envisaged. The experimental equipment is designed and developed which is modular. The automation is built using the motion control card on LabVIEW platform to have a 4 axes, automated, 2 µm accuracy in x, y directions and 50 µm in Z axis with minimum X-Y table speed of 10 µm/sec and tool feed rate of 10 µm/sec. The equipment has the facility of online measurement of the process current and gap voltage. The measured values can be stored over two I/O channels, which can be used for the transient analysis of the process.**

***Index Terms*—micro manufacturing, ECSMM, online measurements, precision, µm/step, electrochemical spark, automated motion control**

I. Introduction

While carrying out the experimental research using electro chemical spark micro machining (ECSMM), a need was felt to have a set-up with the facility to mount the workpiece to be machined on an x-y platform, which can be controlled in micro meter range together with a provision of an automated tool feeding arrangement. Commercial machines available from Micro Tool Company, Bethlehem and Mikrotools, Singapore are way too costlier to afford for experimentation and research purposes. The machines developed as reported in [1], [2] and several others are mostly for the micro-EDM processes. More over access to these machines is impractical. A machine low in cost with the features required to carry out the micro manufacturing was not available off-the-shelf in India hence it was planned to design and develop such a machine.

An automated 4 axes experimental set-up is designed, and fabricated in-house [3], [4] with the following subsystems:

- Machining Chamber,
- Exhaust System,
- LabVIEW based Control Station, and
- Power Supply System.

Fig. 1 presents the block diagram of the complete experimental set-up.

II. ECSMM Experimental Set-up

Machining chamber is the main sub system of the set-up. Exhaust system is provided to take away the fumes generated during the electrochemical spark process. The control station is established on the Personal Computer (PC) using motion control hardware (NI 7358) and supporting accessories (MID 7604, and UMI 7774). Power supply system incorporates the power supplies used for machining, control hardware and for driving the stepper motors.

A. Machining Chamber

The machining chamber is the heart of the equipment; it houses X-Y stage, tool feed and tool holder assembly, Z axis and ECSMM cell sub assemblies.

X, Y, Z and tool feed stages are motorized. The motors used are stepper motors of different torque ratings and design. The motors used in X-Y stage, Z axis assembly are driven by MID 7604 driver interface card, as elaborated in Fig. 1. The stepper motor driving the tool feed stage is configured using a 4-Axis Universal Motion Interface Card, UMI 7774.

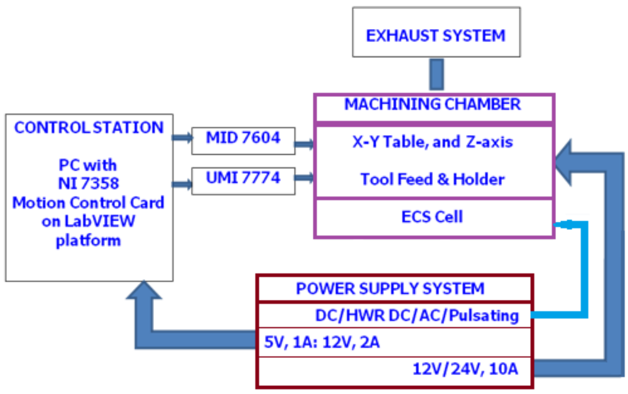

Figure 1. Block diagram of the ECSMM equipment

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X-Y Table: It comprises of X and Y stages. Rotation to the X and Y screws is provided by separate stepper motors. It has resolution of 2 μm/step in X and Y directions, and traverse of 100 mm in both the directions. The guide ways use balls as rolling elements. The mechanical drive is a ground lead screw of 400 μm pitch made of aluminium alloy. Fig. 2 shows the photograph of the X-Y stage. The stage has been fabricated by 'Holmarc Slides & Controls Pvt. Ltd. Edappally, Kochi-682 024, Kerala (www.holmarc.com). The table is mounted on a chrome plated MS plate. Chrome plating protects the plate from corrosion. The top plate has mounting tapped holes of M6 on a 25 mm grid to mount the ECS cell. Bellows are provided to protect the motors from the electrolyte splashes and fumes produced during the electrochemical spark process in operation.

Z axis assembly: The Z axis assembly is automated to move up or down to maintain a constant workpiece-tool gap. The worm and worm wheel with a gear ratio of 1:38 transmit the power to a lead screw of 200 μm pitch. All the parts are fabricated with stainless steel to resist corrosion due to acidic environment. The assembly has positioning accuracy of 50 μm and maximum vertical travel of 80 mm. The assembly has been fabricated by Falcon Industries, Dada Nagar, Kanpur. Fig. 3a shows the complete Z axis assembly. The driving stepper motor and the lead screw with worm gear assembly can be clearly seen in Fig. 3b.

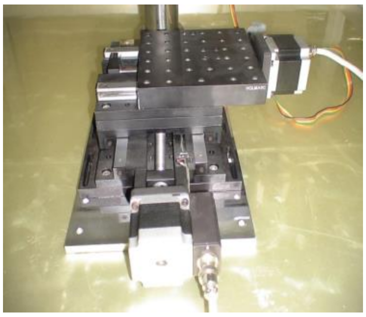

Figure 2. Photograph of the X-Y stage (www.holmarc.com)

Figure 3a. Complete Z axis assembly

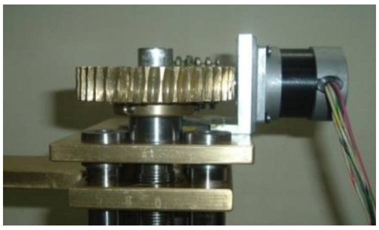

Figure 3b. Driving stepper motor with lead screw and worm gear on Z axis assembly

Tool feed and tool holder assembly: A fixture made of Perspex material is designed and fabricated to hold the tool holder on Z assembly as seen in Fig. 4a. Provisions are made to supply the pressurized electrolyte and air through steel nozzles. Bobbin is provided to have the tool wire reel mounting and driven by a stepper motor with micro stepping capability. This motor has built in electrical drive. In the next version of the tool holder design, glass material with a reduced column length was used. The reduction in the column length facilitated the management of tool wire. It also provided the visual feed back of tool in place. The glass tool holder is designed and developed as seen in Fig. 4b. Moreover use of glass helped in avoiding the electrical short circuiting between the tool holder and tool wire. The glass tool holder also provides the tool insulation and hence reduction in the stray currents. This ensured the good surface finish in the micromachined samples. This is found to be the simplest and cost effective solution to reduce the stray currents and their mall effects on the surface finish.

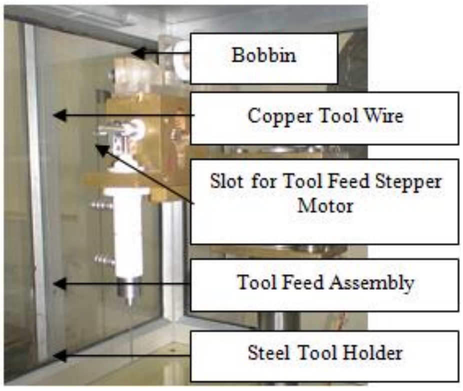

Figure 4a. Photograph of tool feed assembly mounted on Z axis assembly

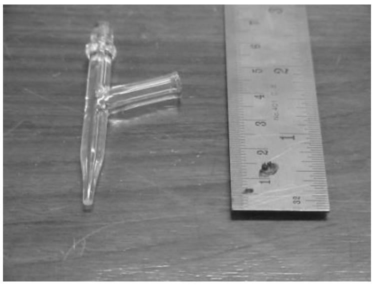

Figure 4b. Glass tool holder

Figure 5. Integrated X-Y, tool feed and Z axis assemblies placed in the machining chamber

Fig. 5 shows the integrated X-Y, Tool feed and Z assemblies together mounted in the machining chamber.

ECSMM cell: ECS cell is a round glass beaker mounted on X-Y stage. It houses the fixture arrangement for graphite anode and workpiece holder. The ECS cell is filled with the electrolyte. The electrolyte level is maintained at 1mm above the flat surface of the workpiece during th experimentation. All the parts (screws, workpiece mounting plate, etc.) in the ECS cell have been made of either perspex or glass material to avoid corrosion and losses due to electrical contacts shorts. Fig. 6 shows the ECS cell with anode, work piece on holder, tool holder etc. In the figure, the spark is visible at the tool tip.

B. Exhaust System

A small DC operated fan is placed in the machining chamber where the fumes are generated. These are carried away by a hose pipe and thrown away from the room with an exhaust fan. This system takes out the fumes generated during the electro chemical actions and provides a safe environment to work.

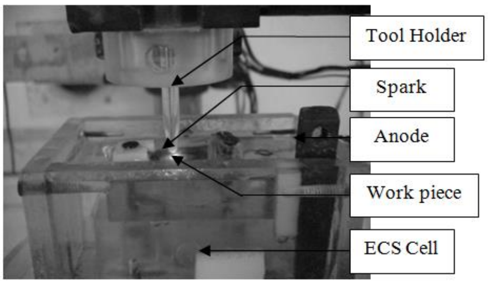

Figure 6. Photograph of the ECSMM cell with graphite anode, copper cathode with spark at the tip and silicon work piece.

C. LabVIEW Based Control Station

The National Instruments LabVIEW (acronym for Laboratory Virtual Instrumentation Engineering Workbench) is used to achieve the control station for the control of ECSMM machine. Stepper motors used for driving X, Y, Z and tool feed are all interfaced to motion controller card installed in PC (Pentium D, 2.8GHz dual core, 256MB SDRAM, 1MB x 2L2 cache memory) via NI UMI 7774, a 4-Axis Universal Motion Interface card. MID 7604 drive board is used to provide the electrical drive for the stepper motors used to drive X, Y and Z axes. The NI 7358 controller is a combination of servo and stepper motor controller for PXI, Compact PCI, and PCI bus computers. It provides fully-programmable motion control for up to eight independent axes of motion. Precise control and drive of the machine is achieved with this motion control card. Fig. 7 gives the control hardware configuration. Contouring functions in LabVIEW 8.2 platform are used to carve different shapes of the microchannels.

Fig. 8 shows the photograph of the control PC (housing motion control card NI 7358), NI driver board and associated power supplies.

Fig. 9 shows the snapshot of the display of contoured machining path followed by the x-y stage.

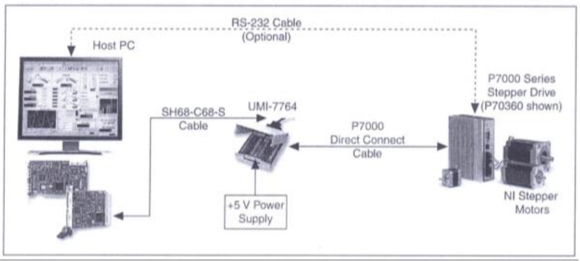

Figure 7. Control hardware configuration (www.ni.com)

Figure 8. Control PC housing motion control card inside and NI 7604 driver board placed on top of the power supplies

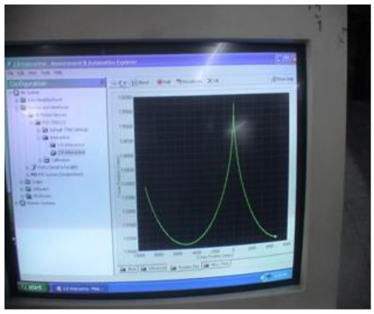

Figure 9. Snapshot of the display of contoured machining path followed by the x-y stage

D. Power Supply System

Power supplies of different ratings are used for driving stepper motors (used for X, Y, Z, and tool feed), supply for control circuitry (on MID 7604, UMI 7774) and for micromachining (across anode and cathode in ECS cell). Use of separate power supply ensures the noise free operations. The power supply used for driving stepper motors are of 12 V, 24 V and of 10 A current ratings. The one used for control circuitry is of 5 V, 1 A and 12 V, 2 A ratings.

Different kinds of power sources have been used for micromachining. The DC power source used has been variable power supply, with voltage varying in range of 10 V–100 V and of 5 A current rating. Other than DC power source, use of half wave rectified (HWR) DC, AC and pulsed DC power source (train of square pulses, and train of triangular pulses) have been used for micromachining.

III. Online Process Parameter Measurements

The time varying process current is measured online by digital storage oscilloscope in synchronization with the voltage. For this purpose the 'resistive shunt method' is used. In this method, a 1 Ohm resistance is connected in series with the cathode and ground of the power supply (Machining power supply, MPS) to the ECS cell. The time varying voltage across this resistance is the direct measure of the time varying process current. The wave forms are saved on the control PC via RS 232 connectivity module of the oscilloscope (Hameg 1008). These synchronized measurements aid in the formation of the transient electrical impedance of the process and help understand the process mechanism. The transient current manifests the sparking phenomenon. This transient current waveform gives the information of the on-time, off-time and the frequency of the sparks occurring during the micro machining process. The occurrences of these pulses directly indicate the correlation between the presence of the sparks during the process and present the quantitative analysis of the process. These parameters are otherwise theoretically estimated. Fig. 10 presents the block diagram of the synchronized, online measurement scheme.

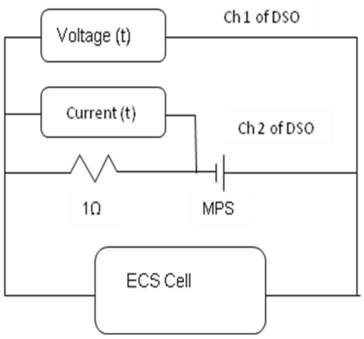

Figure 10. Block diagram of synchronized, online measurement scheme (DSO- Digital storage oscilloscope, MPS- Machining power supply)

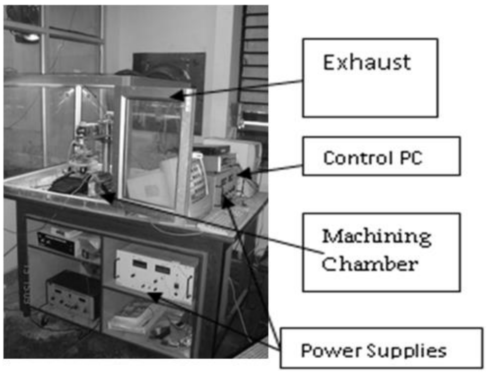

Figure 11. Electro chemical spark micro manufacturing equipment

IV. CONCLUSIONS

The ECSMM micro fabrication equipment has been designed and developed in house at IIT Kanpur as seen in Fig. 11. The prototype cost is around Rupees 8 Lac, which is very cost effective for the precision and automation achieved. The equipment has been successfully used for micromachining of wide range of materials such as copper, platinum, molybdenum, tungsten, tantalum, soda lime glass, quartz, and silicon [5]-[8]. The machine is a versatile in the sense that the same equipment can be used for micro manufacturing making use of the advanced machining processes of the genre of electro chemical, electro discharge and electro chemical spark processes, either for machining or for deposition and surface modification purposes.

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Anjali V. Kulkarni was born in India in June 1962. She completed her M. Sc. in electronics science from Pune University in 1987 and M. Tech. in electrical engineering at IIT Kanpur in the year 2000. She holds Ph.D. degree in electrical engineering from UPTU, Lucknow, India.
She is working as 'Principal Research Engineer' at the Centre for Mechatronics of Indian Institute of Technology Kanpur, UP, India. Advanced machining processes and Mechatronics are her areas of research interest. She has guided three M.Tech students under joint supervision. She has written a book chapter on, "Electrochemical Spark Micromachining Process" and has published several papers in 'Advanced machining processes' and in 'Mechatronics' areas of research. She has filed a group patent. She has worked as the Manager of the prestigious project on 'Jugnu Nano Satellite', a joint venture of IITK and ISRO, which is launched on October, 2011.
Dr. Kulkarni holds membership of IETE, ISAMPE, IEI, and RSI.

V. K. Jain was born in India in Jan. 1946. He completed his M.Tech. in the year 1973 and Ph. D. in the year 1980, both from University of Roorkee, India, in mechanical engineering.
He is currently working as Professor and Emeritus Fellow at Mechanical Engineering Department of Indian Institute of Technology Kanpur. He has served as a Visiting Professor at the University of Nebraska at Lincoln (USA) and University of California at Berkeley (USA). He has also served as a faculty member at MNREC

Allahabad, BITS Pilani, and MREC Jaipur. He has won three gold medals, two silver medals and one best paper award as recognition to his research work. He is editor-in-chief of two Int. Journals and Associate Editor of three Int. Journals. He has been nominated as a member of the editorial board of eleven International Journals. He has also worked as a GUEST-EDITOR for eight special issues. He has more than 200 research publications to his credit. He has written seven books. Dr. Jain holds fellow membership of IEI, INAE and ISTE.