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ECDM, 2D drawing, 3D model, non-conducting materials, Arduino Uno

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DEVELOPMENT AND MANUFACTURING OF ARDUINO BASED ELECTROCHEMICAL DISCHARGE MACHINE

The machining of non-conducting materials is very difficult due to its brittleness and hardness properties. The electrochemical discharge machining (ECDM) process is the hybrid non-traditional manufacturing technology because it is combined with two processes namely electro-chemical machining (ECM) and electro-discharge machining (EDM) which can cut non-conducting and conducting materials. Hence from this view, the present work is undertaken to understand the development and manufacturing of ECDM setup based on Arduino. The 2D drawings are drawn by using AutoCAD software and 3D model is developed with CATIA software. The ECDM machine setup is manufactured accurately according to the 2D drawings and 3D model. The gravity feed mechanism is applied to workpiece materials and the speed of cathode tool electrode is controlled by using Arduino programming through the computer. The preliminary experimental trials were carried out and micro-hole drills on the glass and ceramic materials are successfully achieved. The present article provides fundamental and detailed building study of ECDM setup which includes information from the starting sketch up to the real prototype model. This work may be useful to make advanced machining setup as well as may solve the basic difficulties of new researchers in this field.

1. INTRODUCTION

The hybrid non-traditional manufacturing process namely electrochemical discharge machining is advantageous for machining of non-conducting materials. This process combined with two machining methods viz. electro-chemical and electro-discharge processes [1]. The ECDM process firstly invented by Kurafuji in the year 1968 [2]. The electro-chemical discharge machining can offer 5 to 50 times better material removal than electro-discharge and electro-chemical machining processes [3]. The machining performance of this process depends on various input parameters i.e. tool material, workpiece material, tool size and shape, type of electrolyte, electrolyte concentration, electrolyte temperature, supply voltage, current, duty cycle, distance between cathode to anode, feed rate, pulse duration, electrodes characteristic, wettability, gap between tool and

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workpiece [4]. The various machining operations can be done by using this process such as micro dies, micro drilling, blind holes, machining of cylindrical parts, dressing of micro grinding tools, slicing of glass rods, fabrication of intricate and complex micro profiles [5]. The different applications of this process are the fabrication of micro-filters, microchannels, fabrication of miniature components, repairing of copper tracks on printed circuit boards, heat treatment, arrays of holes in the SU-8 material, surface modification, nanoparticle formation, Hydrogen gas formation [6]. In present research article, the detailed study of development and manufacturing of Arduino controlled electrochemical discharge machine setup based on gravity feed mechanism is explained. Some preliminary experiments were also carried out with this machine. From this machine the micro drilling, microchannel, and cutting operations on conducting as well as non-conducting materials can be done.

2. LITERATURE REVIEW

In this article, the all previous literature related to developments of ECDM machining setup is studied. Most of the researchers have applied gravity feeding mechanism to ECDM machining setup. Whereas, some literature is based on constant feeding mechanism, ultrasonic vibration, the magnetic field to the tool electrode and spring feed mechanism. Gao et al. developed a setup in which workpiece was stable on a stage and immersed in electrolyte container. The gravity feeding device mechanism was applied to the stage which can be propelled and moved on a track [7]. The micro-hole drilling was achieved on Kevlar epoxy composites and glass epoxy composites by using gravity feed aided electrochemical spark machining process [8]. Similarly, drilling hole on the zirconium oxide ceramic material was carried out by using copper tool electrode in the gravity feeding mechanism controlled by ECDM [9]. Likewise, the anode and cathode are positioned on a drill head for controlling the vertical motion and gravity feed contact of the cathode electrode tip towards the workpiece. The electrolyte temperature was controlled and monitored with the help of K-type thermocouple thermometer [10]. Furutani et al. invented a new technique in which gravity feed mechanism was applied to the six electrodes which were arranged radially at the upper holder and in line at the lower electrode [11]. Wei et al. also invented a new technique in which acrylic chamber was fixed on sliding stage which was connected to a counterweight (gravity feed) through a string and supported by a ball bearing pulley. The workpiece was stable on a stainless steel block and dipped in the chamber. The tool rotation was operated by a stepper motor and the displacement sensor was used to measure the machining depth [12]. Similarly, the gravity feed mechanism was applied to the workpiece which was positioned on an acrylic base holder and this holder was fixed on the sliding rail. The cathode tool was clamped in the spindle which can be moved upward and downward directions and rotates at different speeds through the computer control system [13]. Wuthrich et al. made gravity feed spark assisted chemical engraving machining setup in which optical sensors are utilized to know the progress of cathode electrode during the drilling process. However, with the help of voice-coil actuator, the force exerted on the tool can be changed [14]. Similarly, manufactured setup of gravity feed spark assisted chemical engraving which has a feature of monitoring the displacement of the cathode tool electrode. The mini voice-coil actuator applied for tool electrode vibrations [15]. Fascio et al. developed experimental set-up having data acquisition system in which the digitally controlled power supply with data acquisition frequency of 2 kHz was used. The digital Nikon camera was utilized for capturing snapshots of the cathode electrode during electrolysis under different regimes [16].

Jiang et al. fabricated ECDM setup for micro-drilling on soda-lime glass material in which gravity-feed system was applied to the workpiece using the counterweight to provide the constant force. The tool spinning and vibration mechanism were provided with the help of DC motor and a piezo-actuator [17]. The gravity feed applied to a tungsten rod which was held in pin-vice and ultrasonic vibration applied to the soda lime glass material during ECDM micro-hole drilling process [18]. Razfar et al. drilled micro-holes on Soda-lime glass by using Tungsten carbide tool electrode with the gravity feed electrochemical discharge drilling process. The machining depths were measured by using a linear variable differential transformer which was checked and stored on a computer and piezoelectric actuator was used for axial vibrations transferred to the cathode tool [19]. The 1 N feeding force applied to the fixture using a linear guide and the pulley. The linear piezo-actuator assisted vibration on machining tool with the highest pushing force of 3000 N [20]. The constant feed force applied to the tool electrode and using PID controller the Z-axis position can control by driving a voice coil actuator which was fixed on the structure. The force sensor is used for sensing and measuring of tool electrode force [21]. Chak et al. developed the electrochemical discharge machine which offers accurate vertical feed motion to tool electrode in Z-axis and gives controlled rotary motion by using the controller of a stepper motor [22],[23]. Paul et al. fabricated ECDM setup which consists of X-Y axis scanning stage used for the movement of the workpiece in X-axis and Y-axis direction. The feeding mechanism of tool was done by a motorized linear actuator in Z-direction. The electrolyte temperature was regulated and controlled by using a heating rod and temperature controller [24]. Likewise, a setup was developed in which tool feeding was done by a stepper motor and speed was controlled by microcontroller-Arduino through the computer. The decrease in speed was achieved by worm wheel and worm gear arrangement. The worm was attached to the worm wheel and the stepper motor shaft [25]. Similarly, the electrochemical discharge machine setup was built in which 1.2 mm/min feed was obtained to cathode tool with the help of linear motorized actuator [26]. Sabahi et al. developed ECDM setup which combined the chamber process and precise X-Z table. The movement of X and Z-axis controlled by stepper motors. The DC motor was used for providing rotary motion of tool electrode having a range from 0–1500 rpm. In this end-flatted tungsten carbide drilling tool was used for micro drilling on soda lime glass material [27].

Huang et al. manufactured automated ECDM machine in which the maximum speed given to the tool electrode was up to 42,000 rpm with constant feed mechanism [28]. The magnetic field-assisted ECDM was utilized for producing the micro-hole on Pyrex glass using flat sidewall tool. The permanent Nd-Fe-B ring magnet was used for producing the magnetic field in gravity feed ECDM which can improve machining efficiency and accuracy [29]. Coteata et al. made experimental setup in which a slotter-ram of a universal milling machine was used for a mechanical system to interposing the electrical circuit.

The shaft rotary motion of the milling machine is converted in a linear alternative motion through a crank mechanism. The cathode was connected to the rod of the crank [30]. Coteata et al. manufactured hybrid ECDM setup with passivating electrolyte and a rotating tool for drilling process [31]. Singh et al. developed the fixture in which pressurized feeding is applied with compression springs. The workpiece was fixed in this fixture and its function is to maintain the constant working gap because of pressurized feeding. The cathode electrode was manually feed in the direction of work material at the Z-axis [32]. Mediliyegedara et al. developed ECDM process controlled by the algorithm in a software form which can be helpful for to evaluate optimum parameters [33]. Zhang et al. invented tube electrode high-speed electrochemical discharge drilling machine having high precision positioning and precise five-axis motion table. The repeatability of the machine was 0.005 mm and positioning accuracy was 0.01 mm [34]. Furutani et al. manufactured lathe type ECDM in which the normal force at radial direction was controlled from 0.06 to 0.08 N with the help of force sensor at XZ-stage [35].

3. BASIC MECHANISM OF ECDM

The basic mechanism of the ECDM process is represented in Fig. 1. It shows anode and cathode tools are inserted in aqueous electrolyte medium. The cathode surface area is lower than the anode. When D.C. voltage is applied to the cathode and anode electrodes it resulted into the electrolysis takes place between 20 and 30 V. The Hydrogen gas bubbles are developed at the cathode tool electrode and oxygen bubbles are produced at the anode tool electrode. When the voltage is raised then the current also raises which produces a large amount of bubbles and bubble layer around the cathode tool electrode. The utmost voltage goes above the critical voltage then the bubbles coalesce into a gas film to the cathode tool point. Then the light occurs in the film where an electrical discharge takes place between the cathode and the electrolyte [36].

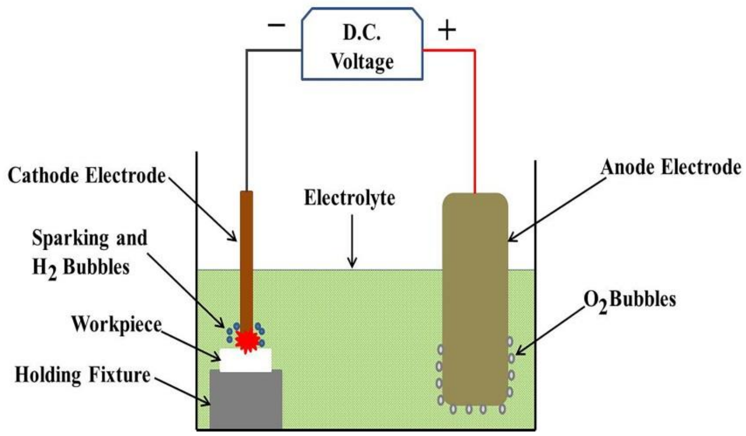


Fig. 1. Basic mechanism of ECDM process

Figure 2 indicates the schematic diagram of ECDM setup. The gravity feed mechanism is applied to the workpiece towards the cathode tool electrode to maintain the constant feed during machining conditions. The cathode tool is connected to the spindle of a stepper motor. The stepper motor is connected to a micro-stepping drive and this drive is interface to Arduino Uno board. The computer is connected to this Arduino Uno board. Depending upon the Arduino programming the stepper motor speed can be varied from 0 to 100 rpm. The D.C. supply voltage is connected to cathode and anode tool which is dipped into the electrolyte solution. The micro drilling and microchannel operation can be done on conducting as well as non-conducting materials by using this machining setup.

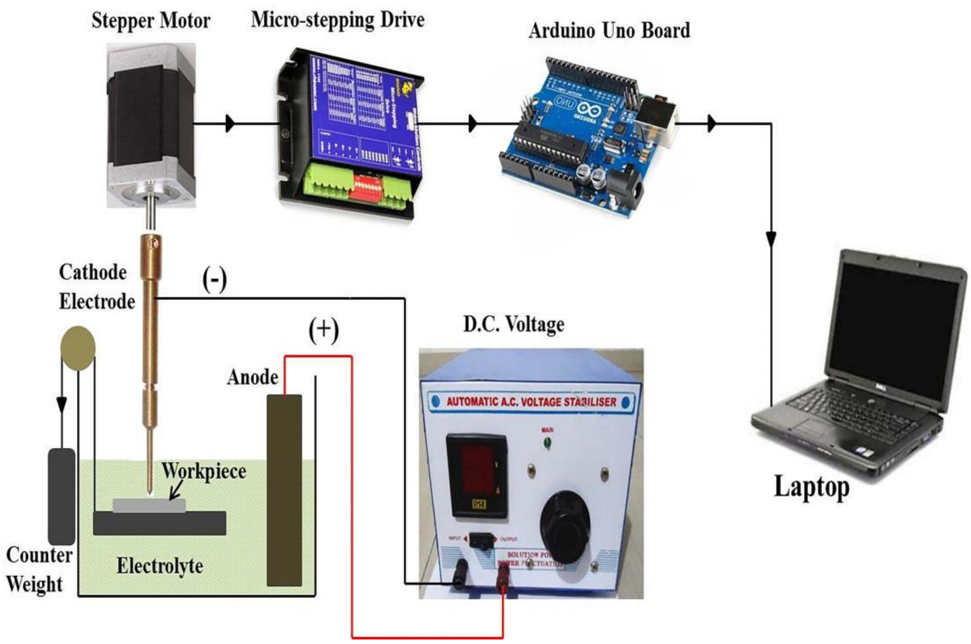


Fig. 2. Schematic diagram of ECDM machine setup

4. 2D DRAWINGS OF EACH PART OF ECDM SETUP

In this ECDM machining setup, there are various parts were used to make a complete machine. The ECDM machine components are categorized into mechanical, electrical and electronics parts. The mechanical parts includes machine table, compound sliding table, single axis sliding table, electrolyte container, stepper motor mounting plate, height piece, welded bracket, workpiece fixture, pulley, pulley bracket, dead weight, cathode and anode tool electrodes. While, the electrical and electronics parts are a stepper motor, micro-stepping drive, Arduino Uno board, power supply (SMPS), D.C. voltage regulator and computer.

Figure 3 shows machine table which is made up of a stainless steel material having dimensions of 1275×630×675 mm^3. The table base plate has the 3mm thickness of mild steel having area of 1275×630 mm^2. The corners of this plate are welded joints to L type channel plate having the length of 675 mm which is supporting the base plate. The total weight of this table is around 50 kg. The all ECDM machine parts are loaded into this machine table.

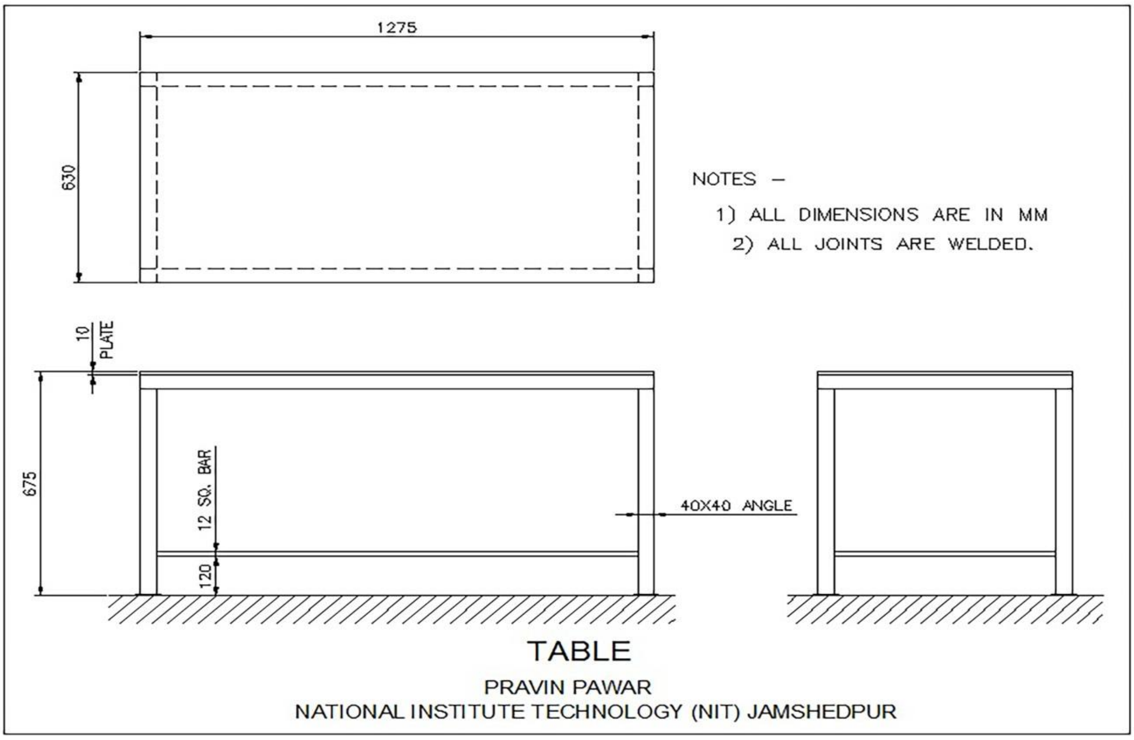


Fig. 3. ECDM Machine table

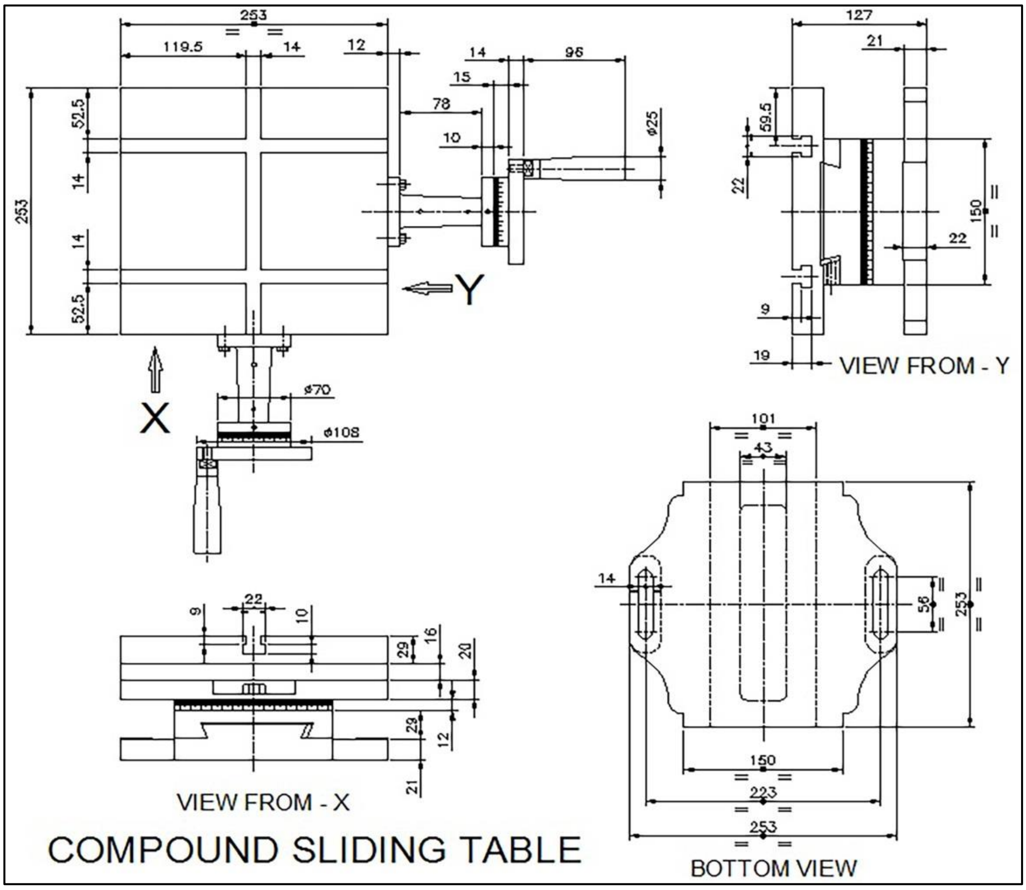


Fig. 4. Compound sliding table

Figure 4 presents the detailed drawing of a compound sliding table which is fixed on the top of machine table. The compound sliding table is made by the combination of cast iron and steel material which is used for sliding movement of X-axis and Y-axis directions. The sliding table dimension is 253×253 mm^2. This table is fixed on the machine table by using nut and bolts. The handle is provided to X-axis and Y-axis for sliding movement. When handle rotates it moves in forward and backward directions because of the lead screw located below the sliding table.

Figure 5 shows electrolyte container, workpiece mounting fixture, pulley bracket and support plate. All these parts are made up of acrylic material. The purpose of using acrylic material is to avoid chemical reaction which cannot effect on this material; therefore, it is used for the making of electrolyte container and mounting fixture. The square-shaped acrylic container has attached four strips at the bottom which is precisely located to fit on the slot of a compound sliding table. The electrolyte container can easily take away and put again whenever required into the slot of the compound sliding table. The workpiece mounting fixture is used to hold the workpiece material size of 125×150 mm^2. The left side of this fixture is attached with wire rope for the purpose of gravity feeding mechanism. The one end of wire rope connected to the fixture and another end is connected to the dead weight. The pulley is fixed on left side strip of the acrylic container using pulley bracket and which is placed in between wire rope of workpiece mounting fixture and dead weight. The wire rope of workpiece mounting fixture can travel up and down direction through this pulley due to dead weight.

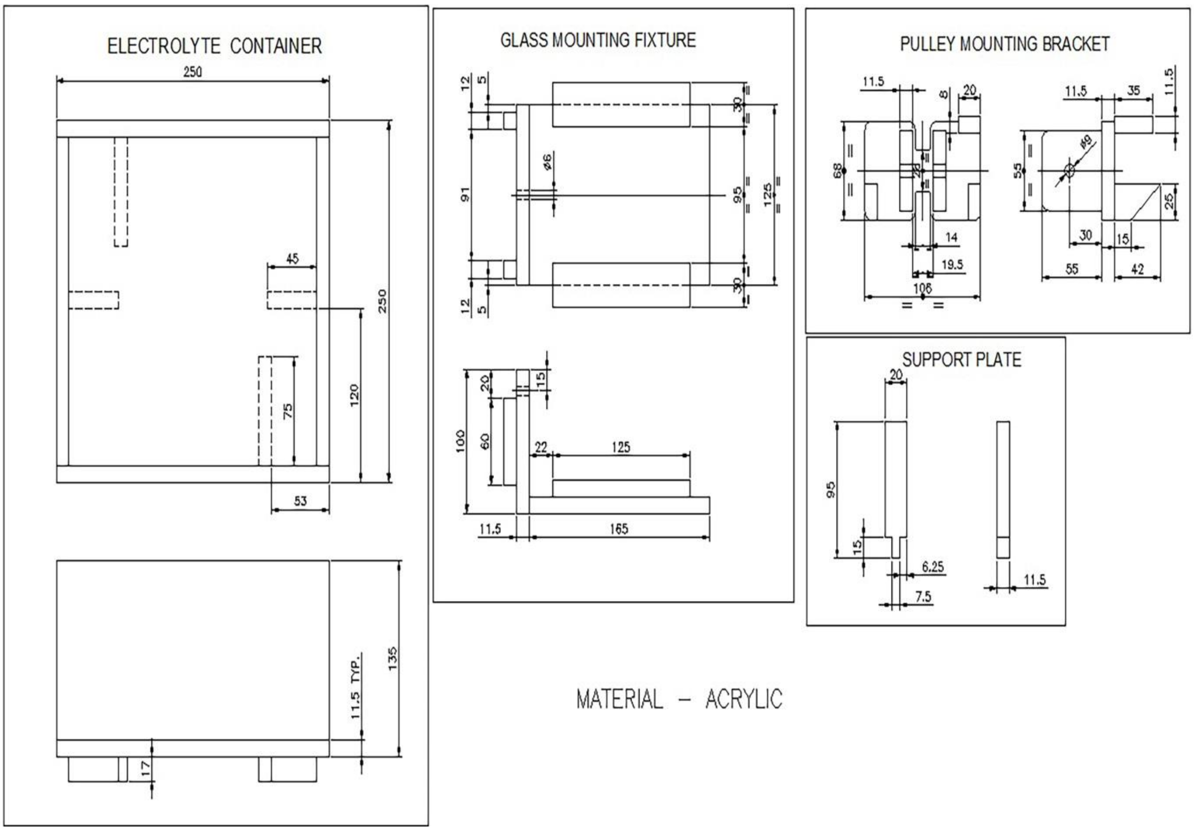


Fig. 5. Electrolyte container, Workpiece mounting fixture, Pulley mounting bracket and Support plate

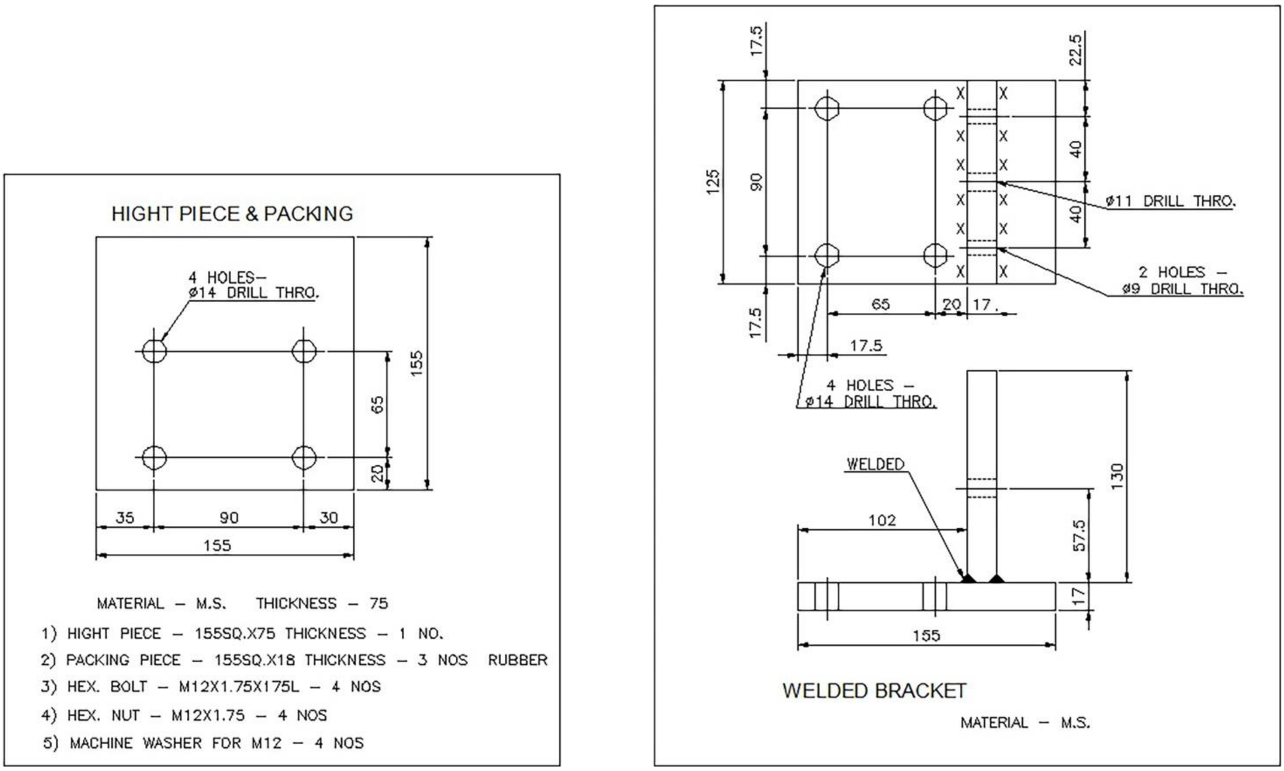


Fig. 6. Height piece and Welded bracket

Figure 6 shows height piece and welded bracket for holding of a single axis (Z-axis) sliding table. The height piece is made up of mild steel square block having area of 155×155 mm^2. The four through holes are drilled on the left-hand side of this block by using drilling machine. This block is fixed in machine table using nut and bolts. The welded bracket is utilized for mounting a single axis sliding table on height piece. The vertical side of the bracket is bolted with the single axis (z-axis) sliding table and the horizontal side of the bracket is bolted to height piece.

Figure 7 shows single axis sliding table which is fixed to a welded bracket. The welded bracket is bolted with height piece and machine table. This single axis sliding table is used for upward and downward movement of cathode tool electrode. The cathode tool electrode is fixed to the stepper motor spindle and this stepper motor is fixed on to the motor mounting plate. The handle of single axis sliding table is coupled with a lead screw which can be used for sliding movement. The table can be moved manually through the handle.

Figure 8 shows motor mounting plate which is made up of aluminum material. The stepper motor, micro-stepping drive, and Arduino Uno board is located on the top of this motor mounting plate. The perfect holes are drilled according to the location of stepper motor, micro-stepping drive, Arduino Uno board and then these are fixed with the help of nut and bolts. This mounting plate is fixed to a single axis (Z-Axis) sliding table. The small rectangular block is joined with mounting plate and these all connected to the single axis slide table with nut and bolts. The mounting plate can be moved upward and downward direction through Z-axis sliding table.

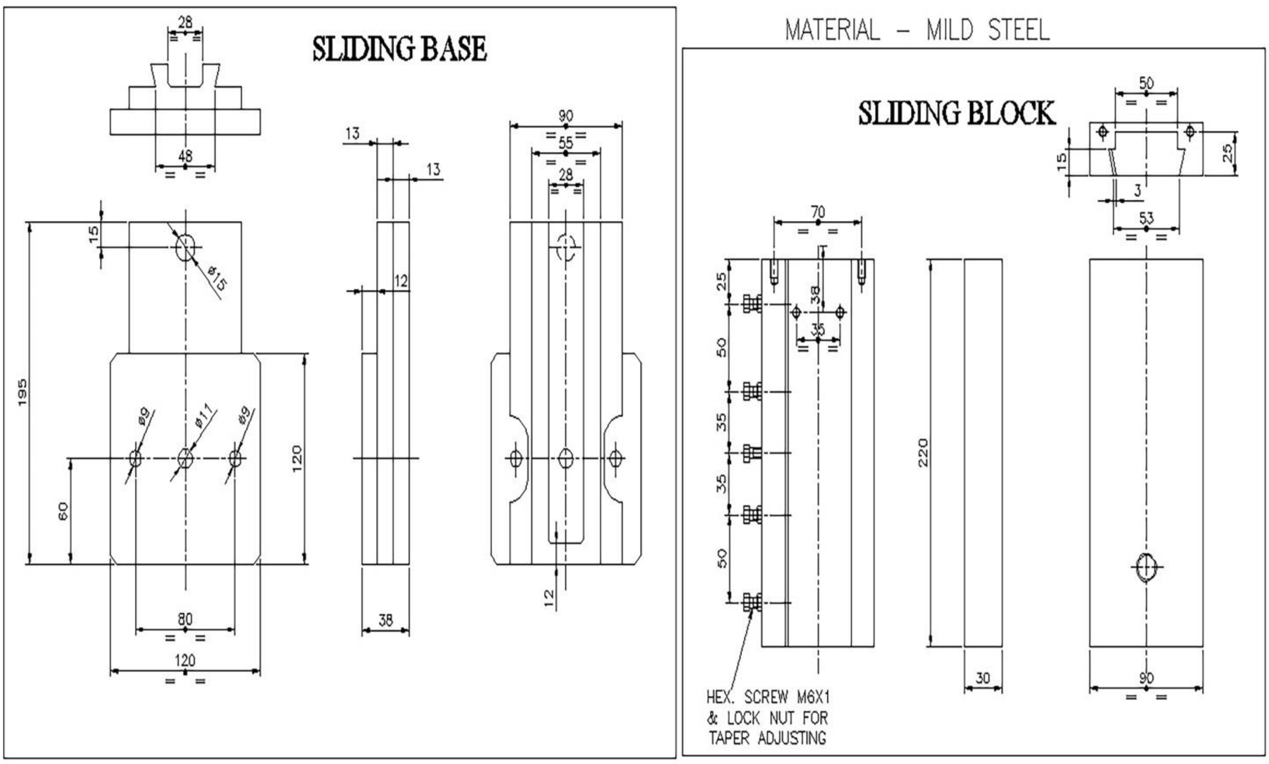


Fig. 7. Single axis (Z-Axis) Sliding Block and Sliding Base

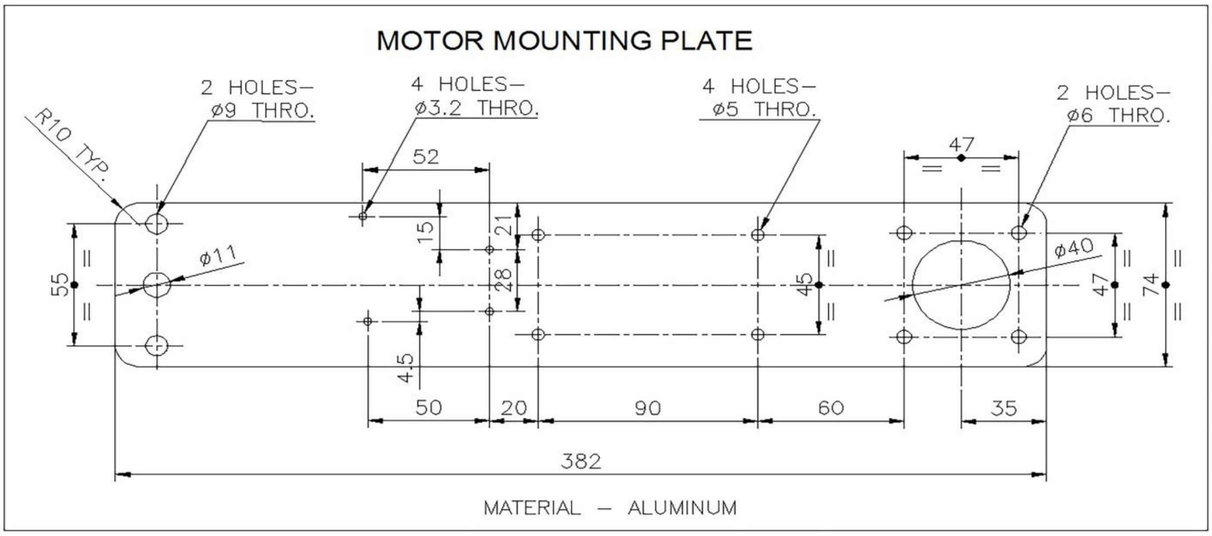


Fig. 8. Mounting Plate for Arduino Uno board, Micro-stepping drive and Stepper motor

Figure 9 shows small components which are the parts of ECDM machine setup. These are handle, plate, flange, clamp plate, and pulley. The X, Y and Z axis movements of sliding table is done manually through the handle attached to the compound and single axis sliding table. The small plate block is used for attachment of mounting plate to Z-axis sliding table. The Flange is the part of Z-axis sliding table which connects the handle to lead screw. The clamping plate is used for holding of an electrode which helps to rotate electrode in straightaway without any vibration. The clamping plate of an electrode is mainly used for applying D.C. voltage to a cathode electrode. The cathode tool with its bearing is fixed in between clamping plate. The cathode tool is rotated in between clamp plate. The negative point of D.C. voltage is attached to clamping plate which transfers voltage to a cathode electrode. The pulley is used for movement of wire rope which is attached to the workpiece holding fixture. The material of pulley is aluminum.

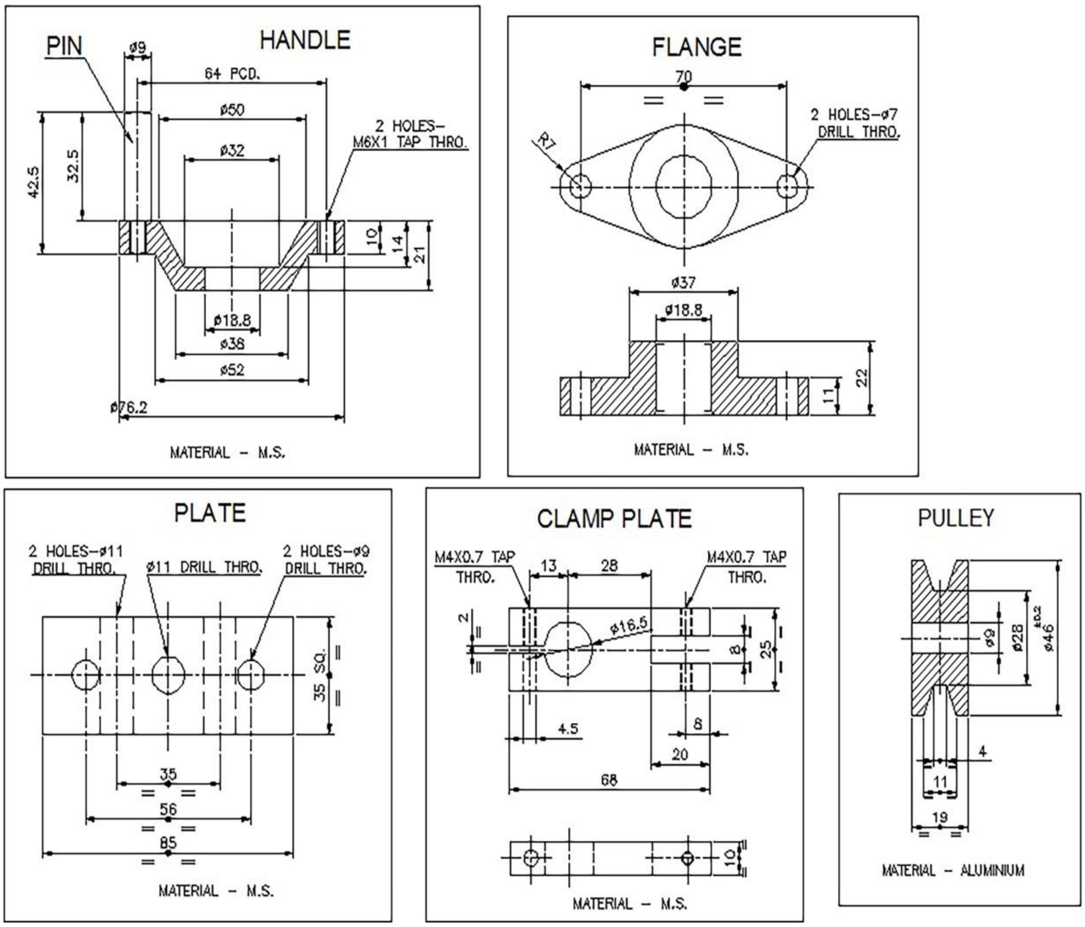


Fig. 9. Handle, Plate, Flange, Clamping plate and Pulley

Figure 10 shows cathode tool electrode which is made up of copper, brass, gun metal and aluminum materials having total length of 150 mm and 3 mm diameter. The conical shape is given to drilling point of the cathode tool electrode. The top of tool electrode provides 6 mm diameter slot for the location of stepper motor spindle. The spindle of a stepper motor is fixed on a slot by tightening of grub screw. The tapping slot is provided below the 6 mm from the top for locating a screw. The needle roller bearing is fixed into the groove of the cathode electrode. The electrode is rotated between needle roller bearing according to stepper motor speed. Whereas, the outer part of needle roller bearing is fixed into the clamping plate. This clamping plate made up of the steel material is the medium between a cathode electrode and D.C. voltage connector for transferring the voltage.

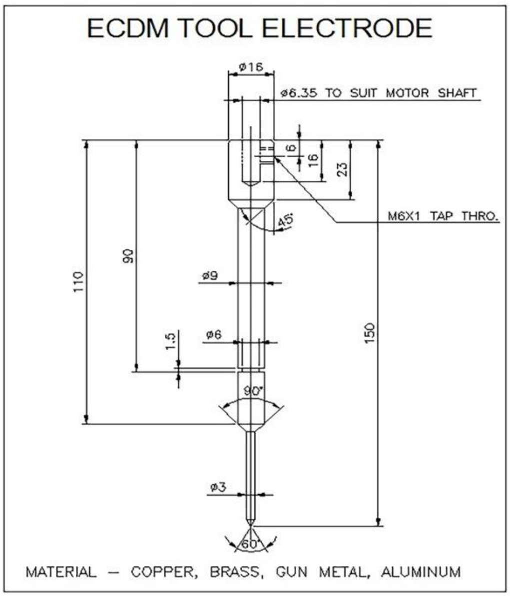
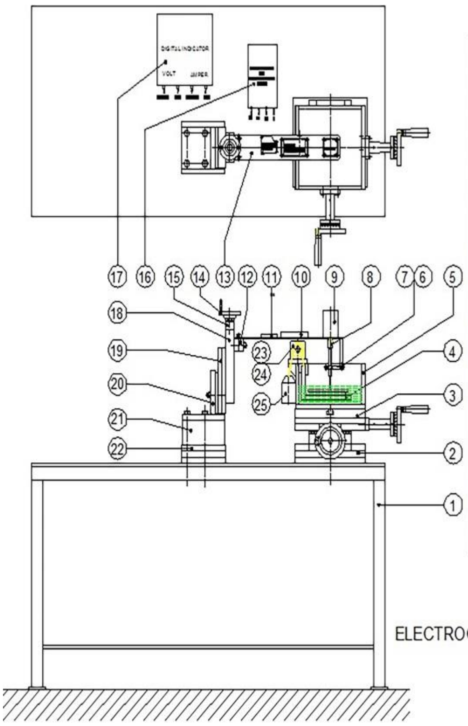


Fig. 10. ECDM Cathode Tool Electrode

Figure 11 shows that assembly of ECDM machining setup which consist of machine table, rubber packing, compound sliding table, workpiece mounting fixture, electrolyte container, supporting plate, clamping plate, ECDM tool electrodes, Stepper motor, micro-stepping controller, Arduino Uno Board, Plate, motor mounting plate, handle, flange and gauge, power supply for stepper motor (SMPS), sliding block, sliding base, welded bracket, height piece, pulley, rubber packing, wire rope, dead weight, mounting bracket etc.



No.	Part Name	QTY.	REMARK
1	Table	1	
2	Rubber Packing	2	
3	Compound Sliding Table	1	
4	Workpiece Mounting Fixture	1	
5	Electrolyte Container	1	
6	Support Plate	1	
7	Clamp Plate	1	
8	ECDM Tool Electrode	4	Copper, Brass, Gun Metal, Aluminum
9	Stepper Motor	1	
10	Micro Stepping Drive	1	
11	Arduino Uno Board	1	
12	Plate	1	
13	Motor Mounting Plate	1	
14	Handle	1	
15	Flange and Guage	1	
16	Power Supply for Stepper Motor	1	
17	D.C. Supply Voltage	1	
18	Sliding Block	1	
19	Sliding Base	1	
20	Welded Bracket	1	
21	Height Piece	1	
22	Rubber Packing	3	
23	Pulley Mounting Bracket	1	
24	Pulley	1	
25	Weight	1	

ELECTROCHEMICAL DISCHARGE MACHINE ASSEMBLY DRAWING

Fig. 11. ECDM Machine Assembly

5. IMPORTANT PARTS OF ECDM SETUP

Figure 12 shows that different mechanical, electrical and electronics components were used for making of complete ECDM machining setup. The power supply (SMPS) for a stepper motor, micro-stepping drive, Arduino Uno board, D.C. voltage regulator, stepper motor, compound sliding table, single axis sliding table, cathode and anode electrodes are the main components of this machine setup.

The D.C. regulator is used to provide digital controlled constant D.C. supply between cathode and anode tool electrodes. The compound sliding table is used for the movement of a table in X-axis and Y-axis direction and single axis sliding table used for vertical movement in Z-axis direction. The electrolyte container is mounted above the compound sliding table in which cathode and anode tool electrodes are immersed. The cathode tool electrode made up of brass material which is fabricated by using conventional lathe machine according to a 2D drawing of the cathode electrode.

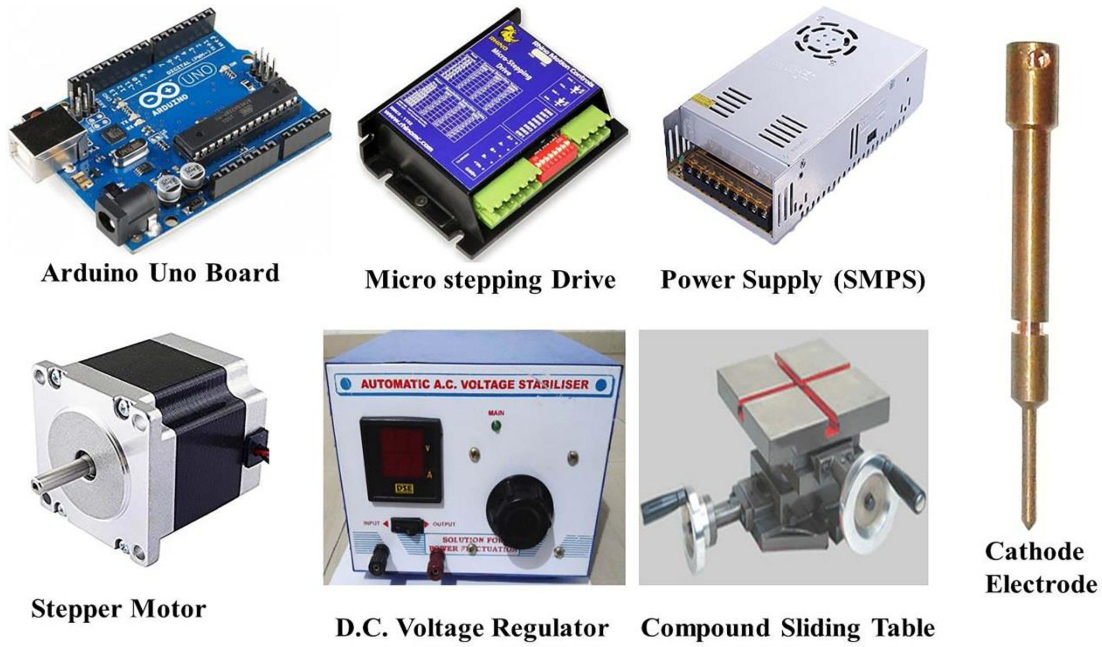


Fig. 12. Mechanical, Electrical and Electronics parts of ECDM machine setup

6. 3D MODEL AND MANUFACTURED ECDM MACHINE SETUP

The 3D model and manufactured ECDM machine setup are shown in Fig. 13. The machine is built exactly according to the 2D drawings which are drawn by using AutoCAD software then a 3D model is developed using CATIA software and finally prototype model is manufactured. The portable and compact size machine is fabricated which can be useful for drilling and cutting operation on non-conducting as well as conducting materials.

The workpiece is holding on holding fixture. The gravity feeding mechanism applied to the holding fixture using wire rope. The electrolyte tank is made up of acrylic material in which anode, cathode electrodes, and holding fixture are immersed. The single axis sliding table positioned vertically which is fixed on height piece. The motor mounting plate made up of aluminum is fixed horizontally on Z-axis single sliding table. The stepper motor, micro-stepping drive and Arduino Uno board are fixed on the motor mounting plate. Due to single axis sliding table, the motor mounting plate can be travel up and down directions. The cathode tool (Brass) is attached to a spindle of the stepper motor and its rotation is operated by using the micro-stepping drive, and Arduino Uno programming code through a computer. The stainless steel (SS 416) rod is taken as anode tool material which is dipped into electrolyte container. The digital controlled D.C. voltage is given between anode and cathode tool electrodes.

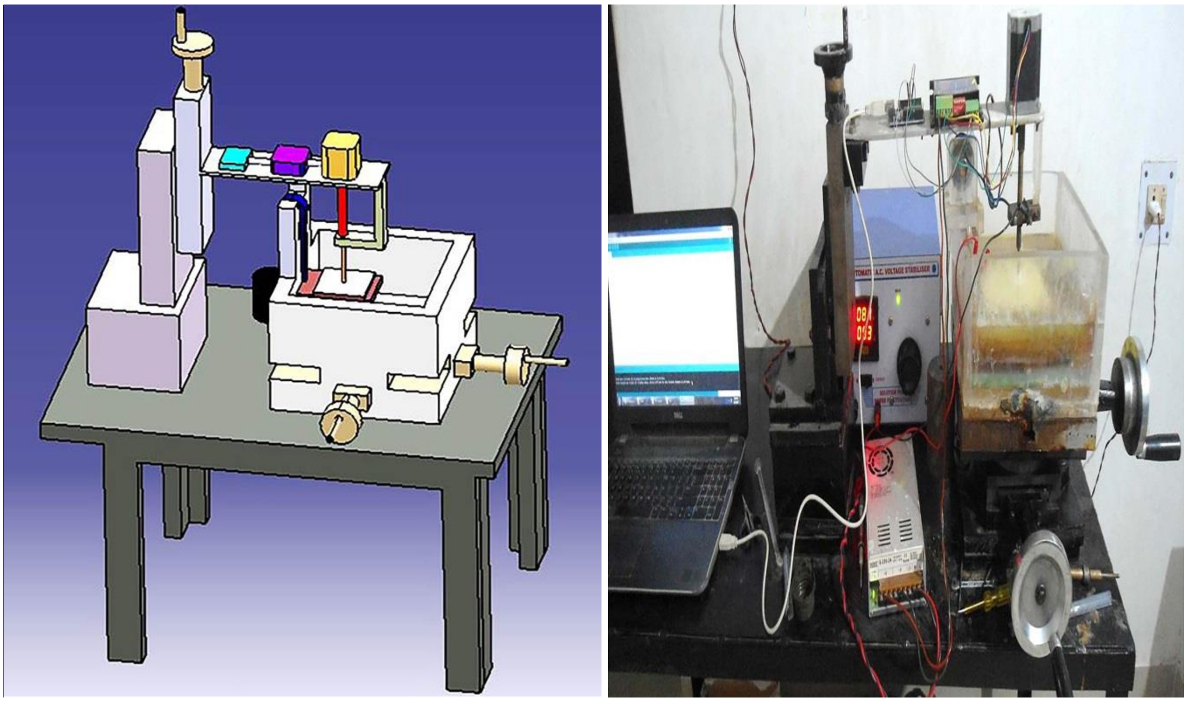


Fig. 13. ECDM Model and Manufactured ECDM machine setup

7. EXPERIMENTAL TRIALS ON DEVELOPED ECDM MACHINE SETUP

The preliminary experimental trials were carried out on developed ECDM machine setup. Figure 14 shows sparking during micro drilling on a glass and ceramic materials and its microscopic images. The developed ECDM machine is successfully working and giving better results also. The experimental trials at the initial stage, input parameters are taken as voltage 80 V, electrolyte concentration is 10% wt., and rotation of 40 rpm. The 3 mm diameter brass cathode electrode, stainless steel (SS 416) anode electrode, and NaOH electrolyte solution were used for experimental trials. The machining time set for each experiment of 25 min. The blind hole was produced on these materials during experiments.

Sparking during micro drilling on ceramic and glass material

Microscopic images of micro holes on ceramic and glass material using ECDM

Fig. 14. Sparking during micro drilling on a glass and ceramic materials and its microscopic images

The machining depth of holes and material removal rate are enhanced when applied voltage and electrolyte concentration is increased. The material removal achieved during these conditions is about 0.84 mg/min for conventional ceramic tile and 0.28 mg/min for glass material. The machining depth of micro-hole for a ceramic material is 1.1 mm and for glass material is 0.22 mm. This machining setup can be useful for developing microstructure on the glass and ceramic materials.

8. CONCLUSION

The non-conducting materials are very hard in nature as they exhibit high hardness and brittleness due to which machining with them is very difficult. Hence, to machine these materials ECDM is the most efficient machining process as it is a combination of ECM and EDM. Therefore, to understand the overall developmental procedure of ECDM setup this study is considered. This article is about the detailed study of manufacturing ECDM setup on the basis of 2D drawings and 3D model. The present study provides the whole fundamental manufacturing details of ECDM setup with its mechanical, electrical and electronic components which will helpful for developing advanced ECDM machining setup. The 2D drawing of each and every part of ECDM setup is provided which will fulfill the material necessity of ECDM setup. The assembly of 2D drawing for ECDM setup is also illustrated with respect to understand the connections of each part. The 3D model will give the idea of an actual prototype of manufactured ECDM setup. The preliminary experimental trails with glass and ceramic materials are carried out and micro-hole drills are successfully achieved with material removal rate and machining depth. This article may accomplish the lacunae of ECDM machining design which can be a challenging task for the upcoming researchers in this field.

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