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Review on Electrochemical Machining Machine

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Abstract

The electrochemical machining process is now days considered one of the best machining strategies for micromachining as it has many more benefits over other conventional manufacturing processes like it does not create defective layer after machining, higher material removal rate, easily machined difficult to machine materials, etc. ECM process is also called a non-traditional machining process based on the principle of "electrolysis". In the present study, a detailed review of different sections of the electrochemical machining process is presented which includes: Ultra-precision motion control for tool positioning, Inter Electrode Gap Control, Electrical Double Layer, design of Power Supply Unit, selection of electrolytes based on the material and its material removal rate, etc. Based on a detailed review of electrochemical micromachining, efforts will be taken to design and developed a novel hybrid setup for electrochemical micromachining machines that will fulfill different industrial needs.

Keywords: Electrochemical machining, electrochemical micromachining, Inter Electrode Gap Control, Power Supply Unit, Material removal rate, Hybrid Electrochemical machining, Electrolysis Electrical Double Layer.

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1. Introduction

Electrochemical machining process is unconventional machining process and used as substitute for different traditional machining processes. ECM is well known and used many times from past years for machining of difficult to machined materials. ECM is working on the principle of electrolysis in which tool-electrode (Cathode) and workpiece (anode) are immersed in electrolyte and voltage is applied in between them which results into passing of current from the system and chemical reaction takes place. The material is removed from the workpiece by mechanism of anodic dissolution and shape of cathode is impregnate on the workpiece.

The present report elaborates upon the work that has been carried out in the field of Electrochemical Machining Machines and would certainly be helpful for new researchers to explore the untouched areas.

2. ECM and Micro ECM machines available in market

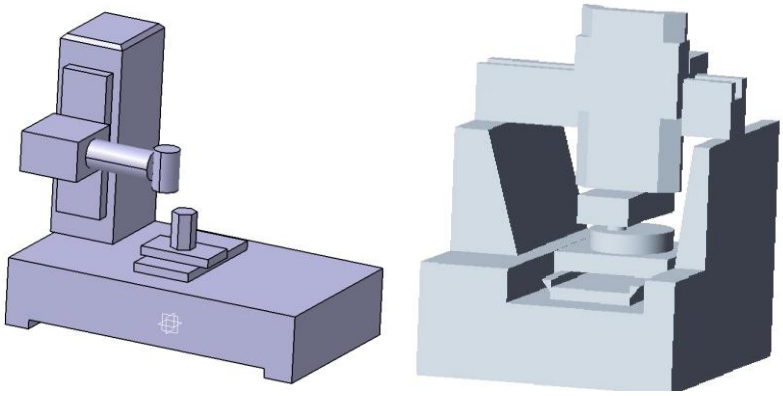
The available ECM machines in the market are most of type of ECM sinking machines and tool electrodes are designed separately for obtaining micro- features. WINBRO group (ECM Manufacturer) manufactured stem drilling machine and die sinking machine. EMAG also

manufactured die sinking machine. Therefore there is no scope for micro ECM in present scenario. There are total four Micro ECM machines which are built up for special purpose application in simplest way. The first machine tool was developed by Li Yong [11] in 2003 for research purpose in China and second machine was manufactured in India by B. Bhattacharya [26]in 2004, while another machine tool was developed by Wang et al.[24] in 2010 for research purpose in China. The Fourth machine was manufactured for industrial application in London by Spieser[25]in 2015.

3. Tool positioning by motion control in Ultra precision way

The dimensional constraint of final manufactured component is mainly depends on the precision of micro-ECM machine. In order to have better material removal rate (MRR), very small gap even less than ten µm is required to be maintained during micro ECM process (Cagnon et al.[1] ,Schuster et al. [2]).

Hou et.al.[3]concluded during their research that closed frame structure for ECM machine provides better stiffness. Their research reported systematic methodology for ultra-precision motion of tool by using linear motor combined with air bearings. This technique satisfy the need of Micro ECM machine for ultra-precision motion of tool as there is no physical contact between tool electrode and work piece which are separated from each other by very small gap and hence ultra-precise motion of tool against the work piece is necessary (Hou et al.[3].



I. Open Frame II. Closed frame

Fig. 1: Two different types of machine structure and coordinate definition (Huo et. al.2010b)

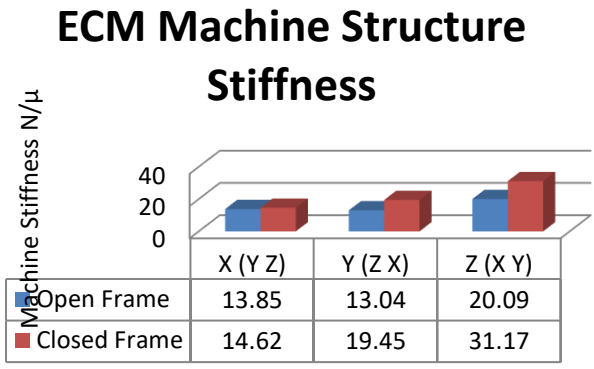


Fig. 2: Structural loop stiffness calculated from static FEA (Huo et al.2010b)

4. Inter Electrode Gap Control

Though there is a huge improvement in Micro ECM process from past ten years but one major problem that is still in under research is controlling and monitoring of Inter-electrode gap.

De Silva[4] gives the significance of Inter electrode gap in ECMM in "Process monitoring of electrochemical Micromachining". In ECM very small inter electrode gap is maintained in order to have high material removal rate. But for maintaining small IE gap between cathode and anode makes process more complicated (De Silva et al.[4]).

The controlling action needs to be taken during the Micro ECM process is because of change in gap between two electrodes. According to the material removal rate and accuracy required during ECM process the Inter electrode gap can be varied from few µm to 50 µm. Also during drilling of micro holes the material removal rate should be equal to the feed rate of tool electrodes against the work piece in order to maintain Inter electrode gap and to avoid short circuits due to physical contact tool electrode with the work piece (Mithu et. al.[5]).

Meijer et. al.[6]during their research proposed because of non-linear behaviour of the ECM process, we cannot used transfer function in case of linear behaviour. But they tried to linearize their proposed methodology of the process to some extent but this process produced an approximation error. Most of time the inter electrode gap was controlled by using binary logic control (Meijer et al.[6]).

Rajurkar et.al. [7] in their study used state space representation method for modelling mathematical model which gives the variation of IEG(1988). But the result of this technique is not mentioned in their study and also this method was not used later on.

Wei et. al. [8] gave strategy for measuring the IEG based on the current response given to pulsed voltage which is used as sensing element in PECM. Because of this strategy, the online measurement of IEG can be possible in real time.

Yong et al.[11] designed new control system which is depends on measuring the current flowing through the system. For controlling the Inter electrode gap between cathode and anode during machining process they feed the electrode against the work piece until the current jump up. When this situation has arrived, the tool is then moved backed by few microns (Yong et al. [11]).

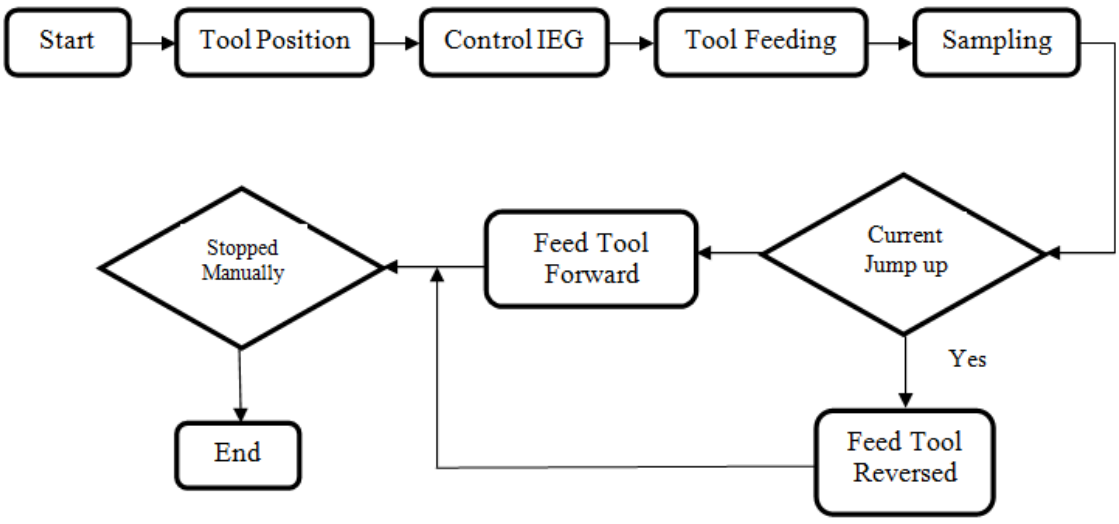


Fig. 3. Flowchart for control of gap between probes (Yong et al. 2003)

5.Electrical Double Layer

During Micro ECM process both electrode and work piece are submerged in electrolyte. The layer of ions is formed between tool- electrode and electrolyte in which it is submerged. This layer of ions will be act electrical barrier and it is commonly known as “Electrical Double Layer”. The Electrical Double Layer is nothing but the voltage difference created between “discharged ions from solution” and “transferred metal ions into the solution”. The Electrical Double Layer is divided into two regions: I. the Helmhotlz double layer which is consider as capacitor and II. The second layer is known as Gouy-Chapman which is also called as “Diffuse layer”. In this layer there is exponential decrease in potential difference with respect to increased distance from the metal layer.

The effect of an Electrical Double Layer in aqueous solution of NaCl is studied by Fuji et al. [12]. They conducted two experiments with two different electrodes. First experiment is conducted with SS (SUS 304) electrode and second experiment using gold electrode. Both the time they used 5 wt. % aqueous solution of NaCl. During the trial, they have been observed that the capacitance of 10.6 µF was measured when DC voltage of 0.3 to 0.5V is applied in Inter-electrode gap and at the time 1V, the capacitance was measured about 34.6 µF. So on the basis of above observed results they stated that the applied voltage is directly proportional to the capacitance of double layer.

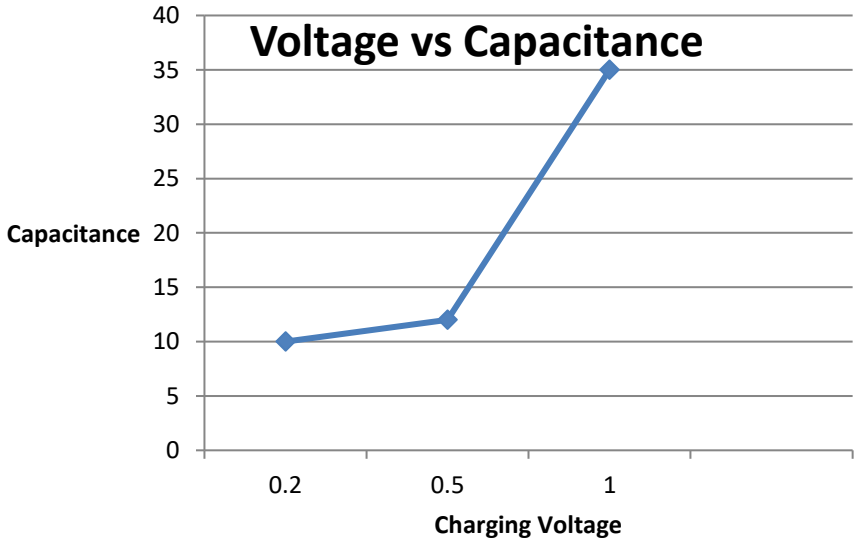


Fig 4: Capacitance is function of charging voltage (Fujii, Muramoto and Shimizu, 2010).

It has been observed that, the behaviour of EDL is very complex. The capacitance of EDL is mainly depends on electrolyte concentration, type of ions in electrolyte, material of electrode and applied voltage between tool and work piece. Therefore the selection of electrolyte is very important and it is mainly depends on the material properties of work piece (Spiecer [19]).

The experiment was performed on PECM with Ultra short pulse model by Schuster et al. for examine the outcome of EDL (Kirchner et al.[13]). Their research suggested that, in ECM process the Electrical Double Layer was properly represented by using capacitor (Ahn et al.[14]). The electrical circuit which they employed for IEG is shown here.

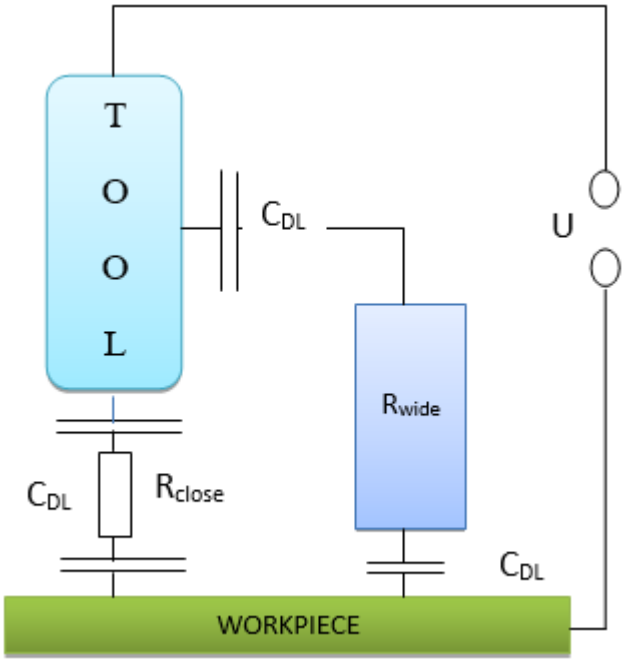


Fig 5: With the help of electrolyte resistance, DLC is charged (Schuster et al., 2000).

The model developed Schuster was modified by Kozak and Marla et al. They added two non-linear resistors in parallel with Electrical Double layer as shown figure.

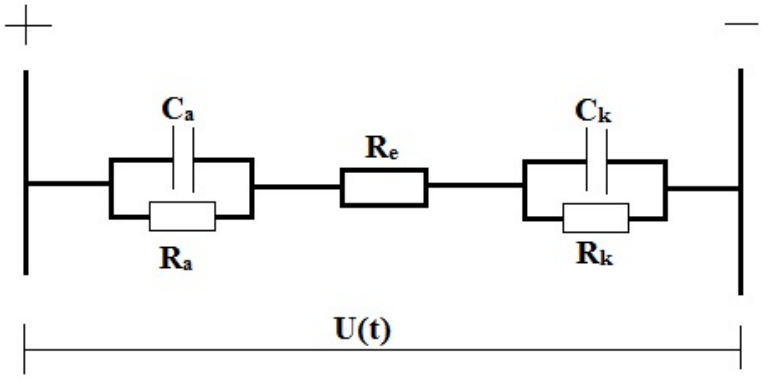


Fig 6: Modern proposed electrical prototype of IEG for micro ECM (Kozak et al 2008) [15]

Their conclusion shows, the addition of two current is the resultant current passing through EDL.
a. Charging Current: The current which is passing through EDL when latter is getting charged is known as Charging Current.
b. Faradaic Current: The current which is responsible for anodic dissolution of material when EDL is completely charged.
Therefore from the above statement it can be concluded that, when current which is used as sensing parameter for Inter Electrode Gap is nothing but Faradaic because it only start passing through the cell when EDL is completely charged so it has relation with IEG resistance. The above prototype was also used by other researchers (Mithu et.al. [10],Ahn et al., 2004 [14]; Fan et.al.[17]).
Kozak et al.[18] during his research combined DC voltage source with pulse voltage source which helps to increase the amount of faradaic current in each pulse which is responsible for removal of

material. In this study, the DC voltage is given to EDL for making it fully charged and never discharge at any time. The voltage pulse is applied between tool and electrode which removes material from work piece efficiently and by same time it also protects the tool from corrosion.

Number of authors used current as sensing parameter for measuring Inter-electrode gap but current is totally depends on conductivity of electrolyte and IEG. The IEG is very difficult to maintain constant and conductivity of electrolyte is also depend on various factors like Temperature, ion concentration etc. Therefore selection of electrolyte and maintain constant properties of electrolyte in IEG is very important, else the agreement among the IE gap and current will be changed.

Also for measuring and monitoring of IE gap, outer surface of tool electrode mostly had isolated to avoid the passing of electric charge along the side walls. The current only flow through from front face of tool electrode and it is used for measuring IEG.

6. **Power Supply Unit**

The power supply unit used during ECM process is two types, a) DC full wave rectified or b) Pulse DC power supply (Bhattacharya et al. [20]). In case of full wave rectified DC power supply, continuous voltage is given between tool and work piece where as in case of pulsed DC power supply, pulse of voltage is given between tool and work piece for only short interval of time. In order to have good surface finish and accuracy during ECM process, pulse DC power supply having very short pulse voltage and high off time is preferred.

The power supply which is required during electrochemical micro-machining is of special type. The pulse of voltage which power supply produced between anode and cathode during ECM process should have following characteristics.

i). Amplitude of pulse is ranges from 0 volt to 10 volts

ii). Up to 5 amp current supply is necessary.

iii). Very high frequency ranges from 10 KHz to 50 MHz (Spicer [19]).

Bhattacharya et al.[20] used power supply having following specification during their study, Current range: - 0 – 10 Volts, current rating: - up to 5 amps. Usually single phase power supply has 220V AC supply, which is then transferred to low voltage and converted into DC supply with the help of single phase transformer and silicon controlled rectified unit. The pulse of required size and shape can be generated by using pulse generator. The power supply has special arrangement which protect the circuit and machine system from damage during short circuit and over loading conditions. The nature of pulse is the measured by using digital oscilloscope provided with main line of power supply (Bhattacharya et al. [20]).

W. Nastu et al. [21] worked on the effect of pulse condition on the fabrication of micro-pins. The power supply they used during their research is of bipolar type power supply having following specification; made of Takasago Ltd. BWS 120-2.5 and digital pulse generator (DF 1906, NF corp.) for supplying constant current between tool electrode and work piece, which stated that the maximum current intensity of pulse was kept constant and the voltage between anode and cathode is changed with respect to Inter electrode gap situation. They concluded that due to the bipolar power supply it minimized the adhesion of oxidized product to the pin surface.

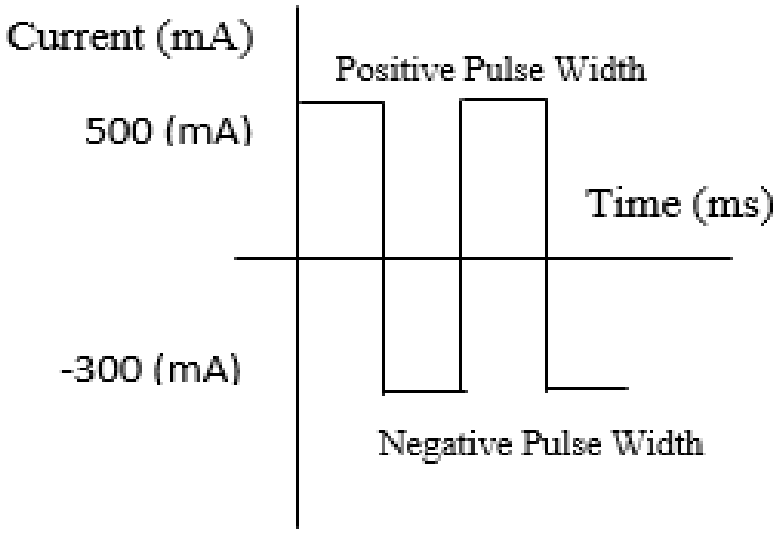


Fig 7: Bipolar current pulse waveform

Li Yong et al. [11] during their research used the pulse power supply which is shown in figure. During the ECM process, samples of current signals and voltage signals are given to identifying element which gives present machining condition and then feedback signal is given to computer which takes corrective decision for controlling micro feeding mechanism. This technique helped to maintained IEG according to condition of ECM process. With the help of output enabling switch, the response of ECM process can be turn on or turn off at any instant by using personal computer. This methodology supports for enhancing the efficiency and accuracy in micro-ECM process by switching off output current during the forward and backward motion of tool for maintaining IEG within limit during ECM process.

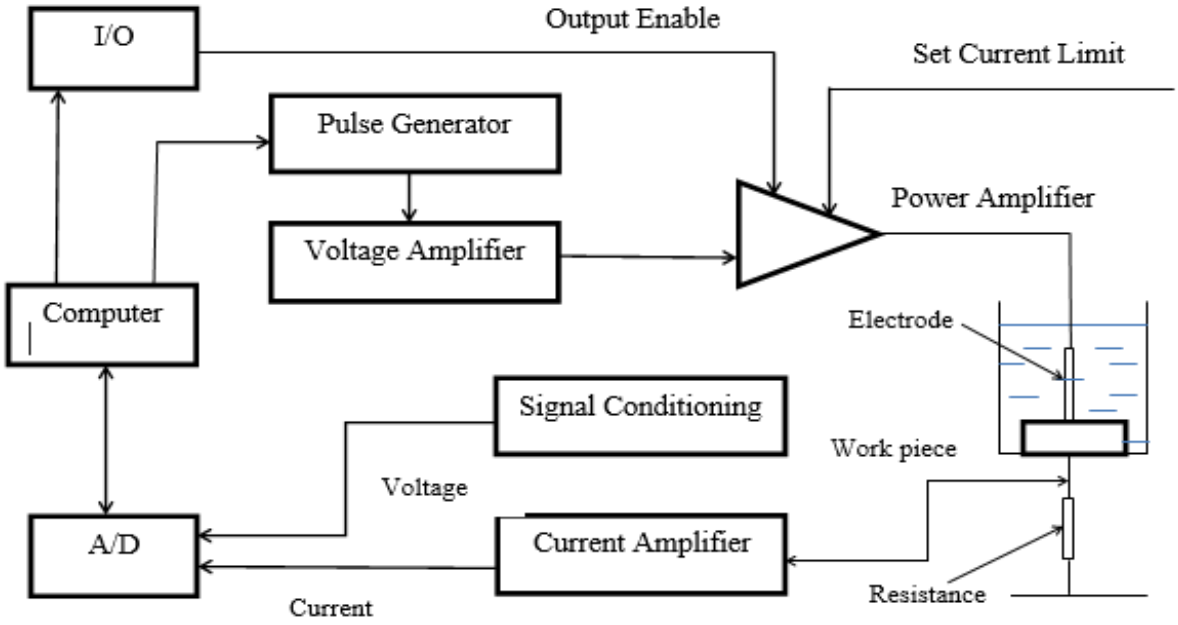


Fig 8: Proposed Pulsed power supply

Min Soo Park and Chang Nam Chu[22] during their study developed new circuit for power supply unit. They used an array of tool for machining of stainless steel, due to this the machining region get

increased which changes the pulse shape. So in order to get desired pulse amplitude, novel dual MOSFET circuit for power supply is created which is shown in figure.

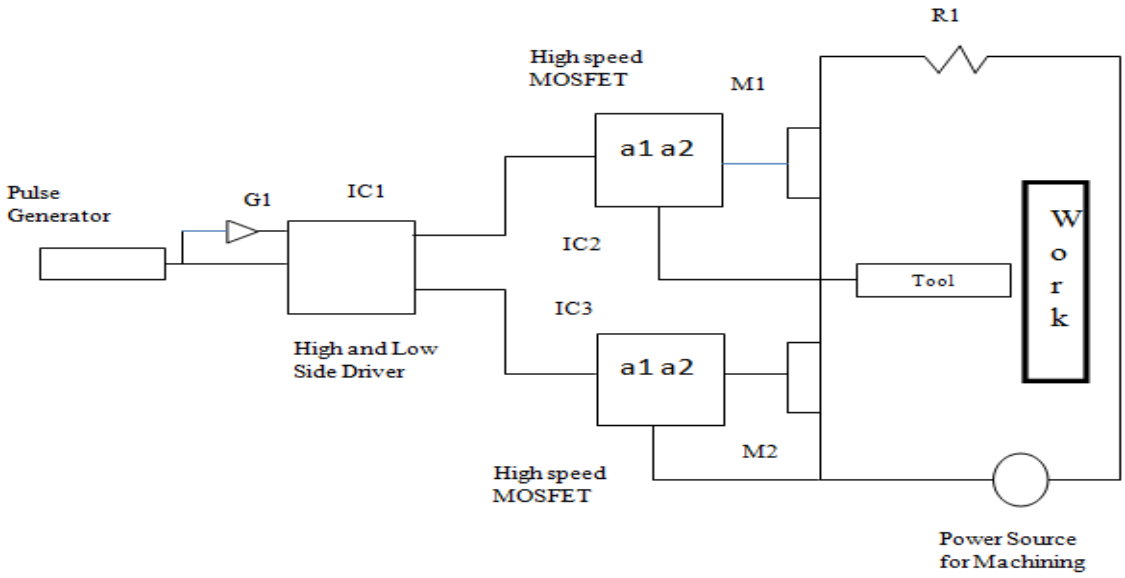


Fig 9: Circuit for dual MOSFET power supply unit.

The novel design for pulsed power supply unit which is needed during process of Micro ECM was developed by Spieser[23] in his research. The developed power supply unit has an ability of provision for negative and positive voltage bias; tens of nanosecond pulse duration and polarity alter capability. In case of short circuit, the wok piece and tool electrode were protected from damaged by provision of ultrafast current protection technique on pulsed power supply unit.

7. Conclusion

In this paper, a detailed review on the past and present research of ECM is presented which includes different areas like ECM set-ups developed by different researchers, precision tool control strategy, measurement and control of inter-electrode gap, effect of electrical double layer, pulse power supply unit and different electrolyte. Based on above overview on ECM, it could be established that there is future scope for hybridization of electrochemical machining machine. So the effortsshould be taken to develop hybrid setup for ECM which will enhance different outcomes of ECM like MRR, surface finish overcut etc.

A conflict of interest- On behalf of all authors, the corresponding author states that there is no conflict of interest

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