Experimental Investigation on the Inner Cavity of Gun Barrel Chamber in Electrochemical Machining

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Abstract

Electrochemical machining (ECM) is a method based on electrochemical process for removing metals in mass productions. In this research, cartridge house inner cavity ECM of a gun barrel, with three deep cavity, is analyzed. So that, according to the various set ups, the optimized machining parameters are obtained. The comparison between ECM and conventional methods from this point of view, shows good advantages of this method, so that, the machining efficiency is more than 15 times less and with very high-surface quality. Besides, the dimensional accuracy of the workpiece repeatability process in this machining method is noticeable. Experimental results indicate that Inner cavity of gun barrel chamber with high precision can be easily done by ECM method.

Keywords: Inner cavity; Gun barrel chamber; ECM; Cathode;

1. Introduction

ECM is one of the well established non-traditional manufacturing processes nowadays. It is a good and effective method in machining of complex shapes [1]. ECM is an important technology in processing difficult-to-cut alloys and to shape free form surfaces [2]. It has been widely applied in aeronautics, aircraft and aerospace industries especially in the blisk which is difficult to cut [3]. ECM is one of advanced machining technologies. Gussef originally proposed and designed the ECM procedure in 1929 [4]. Since then, ECM has been developed and employed in highly specialized fields such as aerospace, aeronautics, defense, and medicine [5]. In recent years, ECM has been used in the automobile and turbomachinery industries because it has no tool wear and can machine difficult-to-cut metals and complex geometries with relatively high accuracy and extremely smooth surfaces manufactured [6]. ECM is based on shaping by controlled anodic dissolution with high-current density. The process is carried out by passing an electric current through an electrolyte flowing within the inter-electrode gap between the tool (cathode) and the workpiece(anode) [7]. Since this machining method is achieved by electrochemical reaction，hard and difficult-to-cut materials can be machined. Various variants of ECM like: electrochemical sinking, ECM with numerically controlled tool-electrode movement, ECM with orbiting tool electrode, pulse ECM, electrochemical deburring and electrochemical polishing are used in industrial practice [8]. Various ECM methods are characterized by high efficiency and lack of tool wear ratio. Moreover, surface of workpiece machined by any of ECM processes is of high quality and stress free. Therefore, usage of ECM for production of dies, parts of turbine and high-compression engines, medical implants, parts for electronic and military industries, etc. is well justified [9]. The form of the gap, and in particular the dependency on gap form with time and process parameters, can be used to determine process characteristics and to define the shape of workpiece surface relative to the tool surface [10]. Recently, another new variant

of ECM in which, a universal tool electrode of simple shape moves along the workpiece surface to obtain a required shape (with this simple electrode which is not congruent with the workpiece shape) has been developed. In recent years, numerous research and development activities have shown that electrochemical micro-machining (ECMM) is a promising technique with flexibilities in ECMM systems and some advanced manufacturing areas [11].

ECM was developed to machine difficult-to cut materials, and it is an anodic dissolution process based on the phenomenon of electrolysis, whose laws were established by Michael Faraday [12]. In ECM, electrolytes serve as conductors of electricity. The rate of machining does not depend on the hardness of the metal [13]. ECM offers a number of advantages over other machining methods and also has several disadvantages [14]. Advantages: there is no tool wear; machining is done at low voltage compared to other processes with high metal removal rate; no burr formation; hard conductive materials can be machined into complicated profiles; work-piece structure suffer no thermal damages; suitable for mass production work and low labour requirements. Disadvantages: a huge amount of energy is consumed that is approximately 100 times that required for the turning or drilling of steel; safety issues on removing and disposing of the explosive hydrogen gas generated during machining; not suited for nonconductive materials and difficulty in handling and containing the electrolyte [15].

This paper aims to present a high efficiency ECM method for inner cavity of gun barrel chamber. Experimental results indicate that inner cavity of gun barrel chamber can be produced at one time with good quality and high efficiency by applying designed ECM device in this investigation.

2. Experimental Procedure

2.1 Fundamental Principles

During ECM, there will be reactions occurring at the electrodes i.e. at the anode or work-piece and at the cathode or the tool along with within the electrolyte [16]. Ion and electrons crossing phase boundaries (the interface between two or more separate phases, such as liquid-solid) would result in electron transfer reaction carried out at both anode and cathode. Meanwhile, the potential difference is fundamental in understanding the energy distribution during the electrochemical machining process [17]. Nernst equation is used to calculate the electrode reversible potential. Tafel equation, diffusion layer, and ohm's law can assist in estimating activation overpotential, concentration overpotential, and resistance overpotential, which are known as the three main overpotentials in electrochemical reactions [18].

It is a function of feed rate which dictates the current passed between the work and the tool. As the tool advances towards work, gap decreases and current increases which increases more metal at a rate corresponding to tool advance [19]. A stable spacing between tool and work is thus established. It may be noted that high feed rate not only is productive but also produces best quality of surface finish. However feed rate is limited by removal of hydrogen gas and products of machining. Metal removal rate is lower with low voltage, low electrolyte concentration and low temperature.
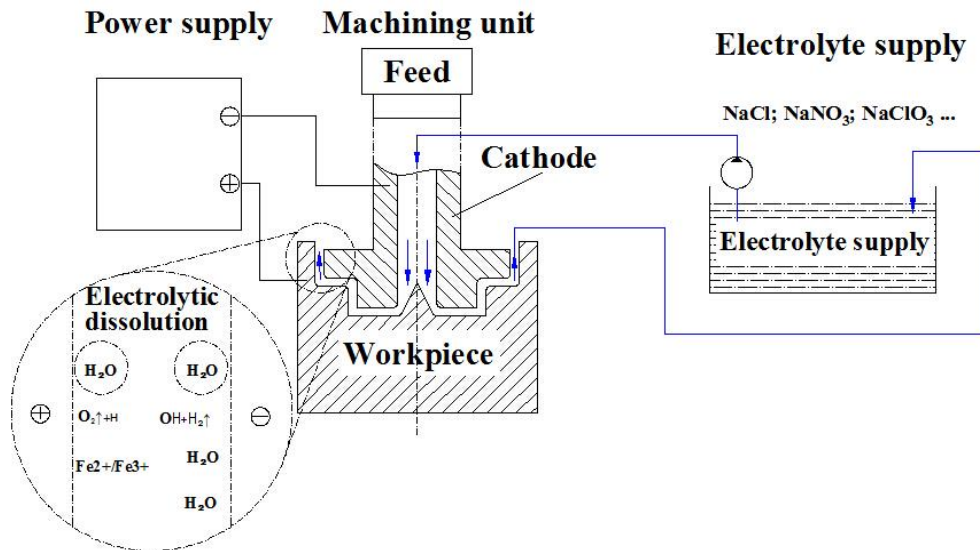
The ECM by a vibrating tool is a major technique in electrochemical technology of machine parts. In constant-feed ECM, the tool moves translationally toward the workpiece. Pumping electrolyte through the inter electrode (IE) gap at a large speed ensures the removal of ECM products (gaseous hydrogen, ions of the workpiece metal) out of the IE space [20]. The current is passing through the system of arrangements will cause the dissolution of anode. The larger gap leads to a decrease in the metal removal rate. Therefore to maintain a constant gap between the tool and workpiece, the cathode

(tool) should be advanced towards the anode (workpiece) at the same rate at which the metal is removed. This process of electrolysis is working based on Faradays law of electrolysis. The principal and experimental system detailing of ECM for steel is shown in Figure 1, generally a neutral salt solution of sodium chloride (NaCl, NaNO₃, NaClO₃) is taken as the electrolyte. The setup consists of three major sub-systems: Machining cell, Power supply, Electrolyte circulation.

ECM is a reproductive forming technique. The material removal principle is based on the anodic dissolution of metals as a result of charge exchanges during electrolysis. The advance in material removal results from the feed motion of the cathodically charged forming electrode towards the anodically charged workpiece which, in contrast to EDM machining, is constant [21]. By the time the machining operation is complete, the workpiece bears the image of the tool geometry. A working gap, through which an electrolyte solution is pumped in order to remove both the Joule effect and the anodic waste products, develops between the workpiece and the tool. The width of this gap depends on the machining rate. The material removal principle is reflected in the three-part structure of the machining facility in Figure 1.

■ Machine tool with feed unit

■ Generator with an automatic voltage regulator and rapid short circuit breaking power

■ Electrolyte supply via pump, tank, temperature and PH-value control and via filter facilities.

The high current densities promote rapid generation of metal hydroxides and gas bubble in the small spacing between the electrodes. These become a barrier to the electrolyzing current after a few seconds. To maintain a continuous high density current, these products of machining must be continuously removed. This is achieved by circulating the electrolyte at a high velocity through the gap between the electrodes.
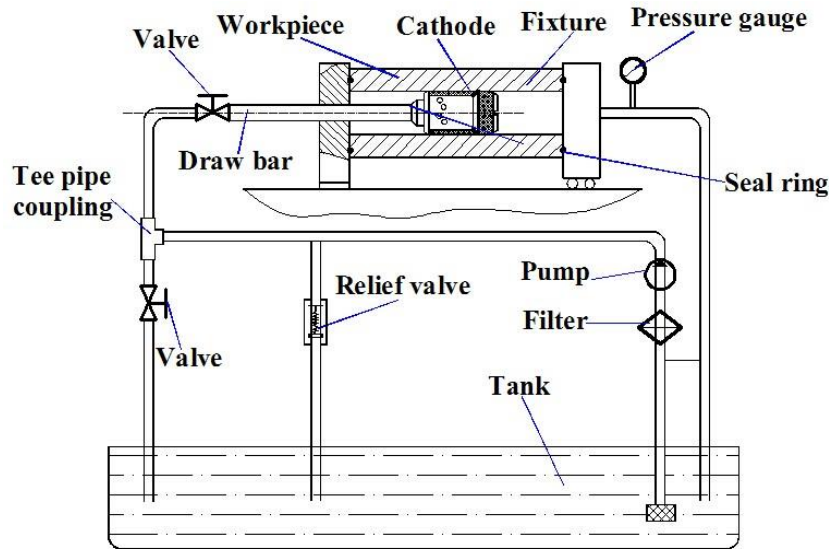

Φιγυρε 1. Τηε πρινχιπαλ ανδ προχεσσ δεταιλινγ οφ EXM

2.2 The Experimental System of ECM

The system consists of three major sub-systems: Machining cell, Power supply, Electrolyte circulation. The developed experimental system consists of tool tubes synchronous movement apparatus, workpiece holder, electrolyte cell, electrolyte supply, power supply, motion control and data acquisition, as shown in Figure 2 shows the details of machining system. The electrolyte is pumped from a tank, lined by corrosion resistant

coating with the help of corrosion resistant pump firstly it fed to filter then it's fed to the job. Spent electrolyte will return to the tank. The hydroxide sludge arising will settle at the bottom of the tank & can be easily drained out. Electrolyte supply shall be governed by flow control valve. Extra electrolyte flow is by passed to the tank. Reservoir provides separate settling and siphoning compartments. All fittings are of corrosion resistant material or of Stainless steel, as necessary.

Φιγυρε 2. Εξπεριμενταλ σψστεμ οφ ΕΧΜ

ΙMachining Cell

The servo system controls the tool motion relative to the work piece to follow the desired path as Figure 3(a). It also controls the gap width within such a range that the discharge process can continue. If tool electrode moves too fast and touches the work piece, short circuit occurs. Short circuit contributes little to material removal because the voltage drop between electrodes is small and the current is limited by the generator. If tool electrode moves too slowly, the gap becomes too wide and electrical discharge never occurs. Another function of servo system is to retract the tool electrode when deterioration of gap condition is Detected. The width cannot be measured during machining; other measurable variables are required for servo control.

The electro-mechanical assembly is a sturdy structure, associated with precision machined components, servo motorized vertical up/down movement of tool, an electrolyte dispensing arrangement. All the exposed components and parts have undergone proper material selection and coating/plating for corrosion protection.

ΙΙPower Supply

The power supply by Pulses current power is a perfect integration of high current electrical, power electronics and precision programmable micro-controller-based technologies. Since the machine operates at very low voltage and high current, there are no chances of any electrical shocks during operation.
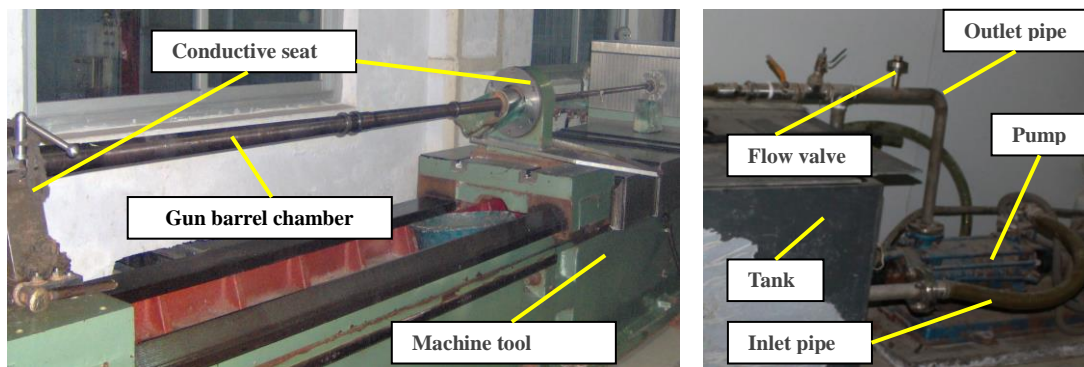
ΙΙΙElectrolyte Circulation

The electrolyte circulation is shown in Figure 3(b). ECM electrolyte is generally classified into two categories: passivity electrolyte containing oxidizing anions e.g.

sodium nitrate and sodium chlorate, etc. and non-passivity electrolyte containing relatively aggressive anions such as sodium chloride. Passivity electrolytes are known to give better machining precision. This is due to their ability to form oxide films and evolve oxygen in the stray current region. From review of past research, in most of the investigations researchers recommended $NaClO_3$, $NaNO_3$, and $NaCl$ solution with different concentration for ECM. The pH value of the electrolyte solution is chosen to ensure good dissolution of the work-piece material during the ECM process without the tool being attacked.

The electrolyte is essential for the electrolytic process to work. The electrolyte has various functions in ECM. These functions are:

■ It carries the current between the tool and the work-piece.

■ It removes the products of machining from the cutting region.

■ It dissipates heat produced in the operation.

■ Electrolytes must have high electrical conductivity, low toxicity and low corrosiveness.

■ The electrolyte is pumped at about 14 kg/cm2 and at speed of at least 50 m/s.

Allowing the electrolyte to flow through the IE gap to remove the solid and gaseous products as well as the heat generated caused by the passes of current and electrochemical reactions. The rates of electrochemical dissolution depend strongly on the temperature. The energy losses in the gap are large but the heat can be removed by high flow of electrolyte and, thus, depends on the geometry. Accordingly the temperature at the anode surface is not exactly known, it can be in the range from 30 to 45℃. The electrolyte is pumped from a tank, lined by corrosion resistant coating with the help of corrosion resistant pump and is feed to the job. The reservoir provides separate settling and siphoning compartments.
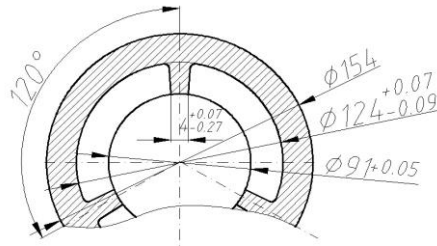

(α) Μαχηινινγ χελλ   (β) Ελεχτρολψτε χιρχυλατιον

Φιγυρε 3. Τηε σχηεματιχ οφ μαχηινινγ χελλλ ιν ΕΧΜ σψστεμ

2.3 Machining Objects

Figure 4 is gun barrel chamber with inner cavity workpiece with higher requirement in its precision. The materials of powder chamber body cavity of barrel is PCrNi3MoV. Processing: thermal refining, $HRC = 40 \sim 50$. Requirements in machining dimension: preformed hole before the polishing is $\phi 91^{+0.05}$ mm, preformed hole after the polishing is

$\phi 124^{+0.07}_{-0.09}$ mm.

Φιγυρε 4. Τηε σχηεματιχ ϖιεω οφ γυν βαρρελ χηαμβερ

The workpiece of chamber body cavity with deep hole and thin wall (as Figure 1 and Figure 2) is inclined to deform in the machining. Nevertheless, the qualified product tends to re-deform for the remnant stress when stocked so that its traits will be severely affected. As regard to ECM, it also reveals some problems, such as, great pressure difference between inlet and outlet, distinguished difference existed in both ends which upright flow direction and central flow field, emergence of flow streamline in the process, which has an effect on the surface quality; furthermore, for the inhomogeneous flow field in the machining gap, its copy precision is low.

Just as obvious impact originates from the gap of ECM as well as the distribution of flow field and electric field on the shaped-precision, surface quality, especially for the complex deep hole. The key to promote machining technique on this sort of products lies in improving the flow field of workpiece with complex deep hole by means of the reasonable design of cathode.

2.4 Machining Parameters

Since gun barrel chamber inner cavity ECM is the finish machining with the given size of workpiece, and its surface roughness of is Ra0.8μm. To realize such a machining accuracy, higher demands are met in the fixture design, devised insulation and seal and whole machining process control except for the accurate design in cathode structure and size. The material of chamber inner cavity is gun barrel PCrNi3MoV. Complexing agent is often put into like NaCl, NaOH and other electrolyte solution to avoid the deposition of dissolved metals on cathode in the processing of alloy or composite materials. Because stray corrosion is serious and machining precision is poor with NaCl electrolyte, $NaNO_3+NaClO_3$ solution is selected in this study for higher machining accuracy inner cavityt. And selecting reasonable machining parameters (as Table 1) is significant to achieve higher machining accuracy and perfect surface quality.

Ταβλε 1. Μαχηινινγ παραμετερσ

Items	Description
Voltage (V)	17
Current (A)	450
Workpiece	PCrNi3MoV
Feed rate (mm/min)	20
Working gap (mm)	0.2~0.4
Initial gap (mm)	0.5
Cathode Material	Brass H62

	Shape	Serial multi-tapered
	Material(solution in water)	$NaNO_3$ and $NaClO_3$
	Component and concentration(%)	$15\%NaNO_3+5\%NaClO_3$
Electrolyte	Pressure(MPa)	1.5
	Electrical conductivity($1/\Omega$mm)	0.016
	Electrolyte temperature	30~35℃

2.5 Cathode Design

The tool must match the required shape of the workpiece depending on the material and the profile to be produced. Tool materials used in ECM must have good thermal and electrical conductivity; corrosion resistance must be highly machinable and should be stiff enough to withstand the electrolytic pressure without vibrating.

As no tool wear takes place, any good conductor is satisfactory as a tool material, but it must be designed strong enough to withstand the hydrostatic force, caused by electrolyte being forced at high speed through the gap between tool and work. The tool is made hollow for drilling holes so that electrolyte can pass along the bore in tool. Cavitations, stagnation and vortex formation in electrolyte flow must be avoided because these result a poor surface finish. It should be given such a shape that the desired shape of job is achieved for the given machining condition.
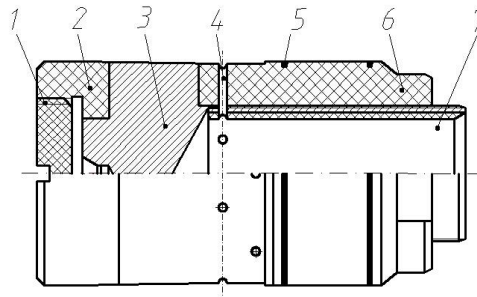
Both external and internal geometries can be machined with an electrochemical machine. Copper is often used as the electrode material. Brass, graphite, and copper-tungsten are also often used because of the ability to be easily machined, they are conductive materials, and they will not corrode.

There are two major aspects of tool design. These are:

■ Determining the tool shape so that the desired shape of the job is achieved for the given machining conditions.

■ Designing the tool for considerations other than e.g. electrolyte flow, insulation, strength and fixing arrangements.

2.5.1 Polished Cathode Design

Mobile deep-hole ECM is applied to polish chamber body inner cavity with the cylindrical tool cathode (as Figure 5). Mobile deep-hole machining tool cathode includes cathode body, fore-end guide sleeve, after end guide sleeve, feed liquid hole, seal ring and connector, and their names and functions are listed as Table 2.

1. Πλυγ 2. Αφτερ ενδ γυιδε σλεεωε 3. Χατηοδε βοδψ 4. Φεεδ λιθυιδ ηολε
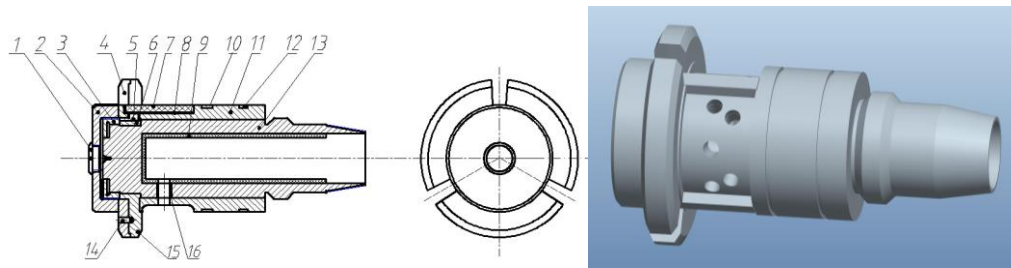
5. Σεαλ ρινγ 6. Φορε–ενδ γυιδε σλεεϖε
Φιγυρε 5. Τηε πολισηεδ χατηοδε φορ ιννερ χαϖιτψ οφ γυν βαρρελ χηαμβερ ιν ΕΧΜ

Ταβλε 2. Πολισηεδ χατηοδε φορ ιννερ χαϖιτψ οφ γυν βαρρελ χηαμβερ

Name	Function
Connector	Connection and conduction
Fore-end guide sleeve	To play a part of guide, location and insulation in the machining process matched with preformed hole
Seal ring	To play a part of seal to avoid electrolyte flowing backward from fore-end guide sleeve
Feed liquid hole	To guide electrolyte passing through the pipe system and draw bar into machining gap
Cathode body	To remove the metal as the cutting edge in the tool
After end guide sleeve	To play a part of location and aerial drainage matched with the machined hole

2.5.2 Cathode Design of Inner Cavity for Gun Barrel Chamber

According to the characteristics of inner structure in chamber body cavity, the design of tool cathode (as Figure 6) can be obtained based on equal gap method.

(α)Τηε 2Δ οφ χατηοδε   (β)Τηε 3Δ οφ χατηοδε
1. Πλυγ   2. Αφτερ ενδ γυιδε σλεεϖε 3. Βλοχκινγ δισκ 4. Ινσυλατιον δισκ 5. ινσυλατιον πι
εχε   6. Φιξεδ ποσιτιον κεψ   7. Ινσυλατιον σλεεϖε   8. Ρυββερ στριπ   9. Ινσυλατιον σλε
εϖε 10. Σεαλ ρινγ   11. Φορε–ενδ γυιδε σλεεϖε   12. Σεαλ ρινγ   13. Χατηοδε βοδψ 14. Στ
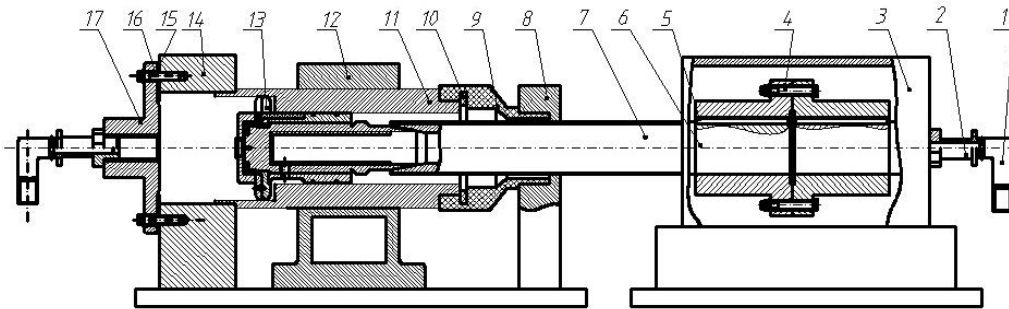οπ πιν 15. Χατηοδιχ δισκ 16. Χατηοδιχ πλυγ.
Φιγυρε 6. Τηε χατηοδε οφ ΕΧΜ φορ ιννερ χαϖιτψ οφ γυν βαρρελ χηαμβερ

2.6 The ECM setup for inner cavity of gun barrel chamber

The ECM setup for inner cavity of gun barrel chamber is shown in Figure 7. Spindle box 3 is fixed on the workbench by the bolt, the coupling inside spindle box connects spindle with the draw bar. Two movements of rotating and linear feeding can be realized by the rotation of spindle box driving the draw bar. The electrolyte enters along the hollow draw bar via the pipe joint 1 in feed liquid pipe and flows into machining area via the feed liquid hole in cathode 13. Insulating board installed in the bottom of fixtures 14 and fixture 12(as Figure 8) can realize the insulation with workbench.
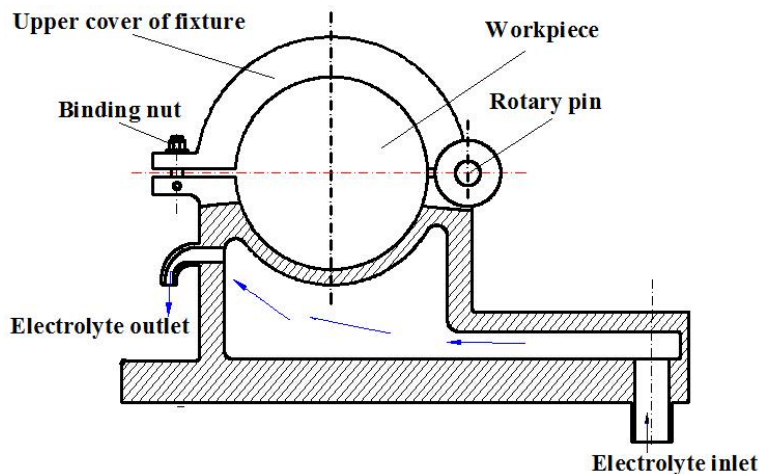
The fixture is used to ensure the machining accuracy in ECM. The inner hole of fixture fits external profile of the chamber body parts to fix by clamping one side of chamber body. The conductivity of workpiece and cathode must be taken into account to ECM fixture. The fixture base connecting with positive electricity can realize the workpiece conductive, while machine tool spindle connecting with the negative electricity can realize cathode conductivity.

The fixture 14 is shown in Figure 7 and its inner hole fits the external profile of the workpiece. The external profile end face of the fixture 14 with 6 threaded holes is connected by the bolt and is sealed by the O-ring. Two threaded holes in the side of fixture are used to connect copper platoon to conduct electricity for the wokpiece.

1. Ελβοω πιπε φοιντ   2–Πιπε φοιντ   3. Σπινδλε βοξ   4. Βολτ 5. Χουπλινγ   6. Κεψ 7. Δρα ω βαρ 8. Φιξτυρε βοδψ 9. Σεαλ χαρτριδγε 10.Σεαλ γασκετ 11. Χηαμβερ βοδψ   12. Φιξτυρ ε βοδψ 13. Χατηοδε 14. Φιξτυρε βοδψ 15. Σεαλ   16. Βολτ   17. Φλανγε πλατε

Φιγυρε 7. Τηε σχηεματιχ πιεω οφ σετυπ φορ ιννερ χαπιτψ οφ γυν βαρρελ χααμβε ρ

One side is revolute fixture 12 (as Figure 8), and the inner hole fits external profile of the workpiece, so it is easy to clamping the workpiece. The coolant liquid can be inlet into the fixture 12 since it is hollow inside. The coolant liquid flows in from the bottom inlet hole on the right side and out from the outlet on the left side, and finally goes into coolant pool. Cooling process is indispensible to ensure the ECM machining quality and accuracy of chamber body inner cavity because a great amount of heat generated may raise the temperature of electrolyte with larger current in machining. The insulating board installed between fixture 12 and workbench makes insulation protection of workbench come true, avoiding the corrosion on the partial surface of fixture 12.

Φιγυρε8. Τηε Χονδυχτιπε σεατ οφ ΕΧΜ φορ ιννερ χαπιτψ οφ γυν βαρρελ χηαμβ ερ

The sample piece of inner cavity of gun barrel chamber machined in ECM and it is cut by Wire Electrical Discharge Machining (WEDM) into thin slices of 0.8mm thick as Figure 9.

Φιγυρε 9. Τηε σαμπλε πιεχε οφ ΕΧΜ φορ ιννερ χαϖιτψοφ γυν βαρρελ χηαμβερ

3. Conclusions

In this research, a high efficiency ECM method and device of □inner cavity of gun barrel chamber is presented. The machining accuracy of inner cavity is ±0.06mm before machining and it is ±0.01mm after machining and surface finishing is 0.8μm before machining and it is 0.2μm after machining by ECM in this research. This research shows that the inner cavity of gun barrel chamber can be machined via set up experimental conditions of ECM.

Acknowledgements

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