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Design on ECM Device for Chamber Body Cavity of Gun Barrel

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ABSTRACT

Electrochemical machining (ECM) is a method based on electrochemical process for removing metals in mass productions. In weapons industry, the project of ECM of chamber body cavity was put forward for its high precision and no cutting stress. According to research object—chamber body cavity, ECM device was designed, which were the inner cavity of ECM. Thereinto, with the use of the parallel gap method, the polishing cathode and the processing cathode of the complex inner cavity were designed; in consideration of the design of the two sets of fixture were done for the external shape of chamber body, and the base of the fixture should be equipped with a conductive seat; in addition, what needed to be considered were the relative problems of the electricity conduction, the feed liquid, the flow distribution and the insulation sealing between work pieces and fixtures. Among them, the method of the feed liquid lies in side streaming; the conductive method was to transmit the electric current to the workpiece through the galvanical fixture, and the conduction of cathode was through the draw bar which connected to the spindle. Under the fixture seat, an insulating board was added to bring about the insulation effect. The way to prevent the electrolyte from overflowing is to fill the gap between the draw bar and the end face of the fixture with a sealing gasket. Experimental results indicate that chamber body cavity can be produced at one time with good quality and high efficiency.

Key words: Chamber body cavity, Device, Gun barrel, ECM, Cathode.

INTRODUCTION

Electrochemical machining (ECM) is an advanced machining technology. ECM has seen a resurgence of industrial interest within the last couple of decades due to its many advantages such as no tool wear, stress free and smooth surfaces of machined product and ability to machine complex shape in electrically conductive materials, regardless of their hardness [1]~[3]. It has been applied in highly specialized fields such as aerospace, aeronautics, and medical industries. ECM is one of advanced machining technologies. Gussef originally proposed and designed the ECM procedure in 1929 [4]~[5]. Since then, ECM has been developed and employed in highly specialized fields such as aerospace, aeronautics, defense, and medicine[6]~[8]. It is a non-traditional machining (NTM) process and is opposite of galvanic coating or deposition process. Thus ECM can be thought of a controlled anodic dissolution at atomic level of the work piece that is electrically conductive through an electrolyte which is quite often water based neutral salt solution[9]~[11]. Because of various complex physic-chemical and hydrodynamic phenomena that occur in the machining gap during the course of machining, the machining rate at any instant depends not only on the end gap, but also on cathode and ECM device [12].

Thin deep hole are among the most innovative and challenging components in modern artillery, deep spline and chamber body cavity. They could reduce weight obviously and significantly improve efficiency and reduce fuel consumption [13]. Chamber body cavity of gun barrels is usually made of Special Purpose steel or Ni-base superalloys which are extremely difficult to be machined. Moreover the shapes of these chamber body cavity profiles are very complex, so it is very difficult to achieve the required component by traditional methods such as cutting processes [14]~[16]. The ECM method is quite effective and accurate to obtain a required shape of work-piece within a given tolerance on the shape and dimensions using the cathode-tool electrode with a shape which is geometrically close to the final shape of the workpiece [17].

This paper aims to present a high efficiency ECM method and device of chamber body cavity in which cooper as cathode tools move towards workpiece parts with appropriate feed rate and the electrolyte is ejected from the outlets of the preformed hole walls to the workpiece to electrochemically produce three chamber body cavity simultaneously. The shape and structures of electrolyte outlets on the preformed hole wall are also optimized for distributing the electrolyte flow more uniformly. Experimental results indicate that chamber body cavity can be produced at one time with good quality and high efficiency by applying designed ECM device in this investigation.

EXPERIMENTAL SECTION

2.1 THE PRINCIPLE AND EXPERIMENTAL SYSTEM OF ECM

ECM process is quite similar in concept to electrical discharge machining with a high current passed across its inter-electrode gap through the electrolyte, a material removal process having a negatively charged electrode (tool cathode), conductive fluid (electrolyte), and a conductive workpiece (anode), however in ECM there is no tool wear [18]. The ECM cutting tool is guided along the desired path very close to the work but it does not touch the piece. Unlike EDM however, no sparks are created. ECM is an electrochemical process in which the work piece acts as an Anode and the tool acts as a Cathode [19]~[20]. An electrolyte generally sodium chloride or sodium nitrate with a velocity of 5~50 m/s is supplied through the concentric hole in the cathode and it falls over the anode surface, a small gap of 0.05~1mm is provided in between the two electrodes. When a small voltage of 5~30V is applied across the inter electrode gap, a high current density of the order of 5~100A/cm2 is producing which results in dissolution of metal from workpiece as anode electrochemically and gas generation occurs at tool cathode.

ECM is the controlled removal of metal by anodic dissolution in an electrolytic cell in which the work piece is the anode and the tool is cathode. ECM is developed on the principle of Faradays and Ohm [21]. In this process, an electrolyte cell is formed by the anode (workpiece) and the cathode (tool) in the midst of a following electrolyte (as Fig.1). The metal is removed by the controlled dissolution of the anode according to the well-known Faradays law of electrolysis. Figure 1 shows two electrodes which are placed closely with a gap of about 0.5mm and immersed in an electrolyte which is a solution of sodium chloride (common salt).

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. It is also to be noted that the machining gap size increases as the metal is removed. 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.

ECM removes material from the work piece by electrochemical process. The working principle is anodic dissolution in which the workpiece as anode and the tool as cathode. Both electrodes are immersed in the electrolyte and electrical applied to these electrodes. The electric conduction is achieved through the movements of ions between the anode and cathode through the electrolyte. The current is passing through the system of arrangements will cause the dissolution of anode. 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 Fig.1, generally a neutral salt solution of sodium chloride ($NaNO_3$+$NaClO_3$) is taken as the electrolyte. The setup consists of three major sub-systems: Machining cell, Power supply, Electrolyte circulation.

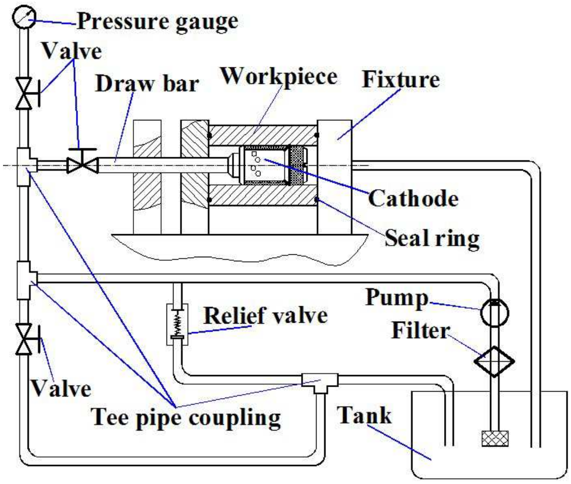


Fig.1: Experimental system of ECM

□Machining cell

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.

– Tool area- 6800 mm2
– Cross head stroke 8000 mm
– Tool feed motor DC servo type

□Power 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.

– Electrical output rating 0~8000A. DC at any voltage from 0~30 V
– Tool feed rate 0.2 to 50 mm/min
–Supply 415 v±10%, three-phase AC, 50 Hz
–Frequency is 1~10 kHz, duty ratio is 0.45~0.8

□Electrolyte circulation

Allowing the electrolyte to flow through the inter-electrode 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 40 to 85□. 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.

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 1 shows the details of machining system.

2.2 RESEARCH OBJECTSesearch objects

The object unfinished powder chamber of barrel which is shown in Fig.2. Fig.3 is powder chamber of barrel with inner cavity workpiece with higher requirement in its precision. The materials of powder chamber body cavity of barrel is 40CrNi3MoV. Processing: thermal refining, $HRC = 36 \sim 38$. Requirements in machining dimension: preformed hole before the polishing is $\phi 81.2^{+0.07}_{-0.05}$ mm, preformed hole after the polishing is $\phi 82^{+0.09}$ mm; total length of workpiece is $278^{+0.8}_{-0.1}$ mm, the length of the machined part is $228^{+1.2}_{-0.8}$ mm.

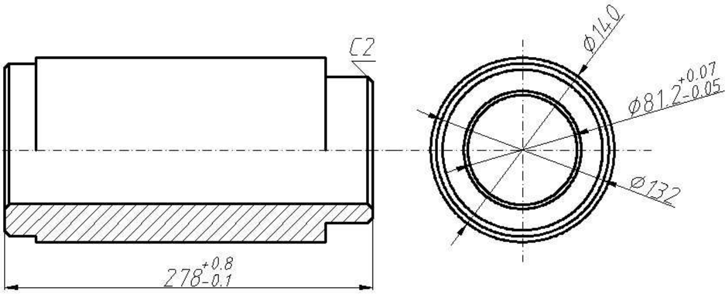


Fig.2: The part drawing of preformed hole for chamber body cavity

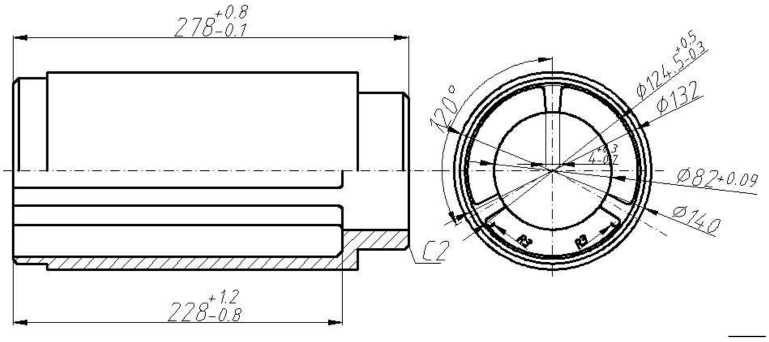


Fig.3: The part drawing of chamber body cavity

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.

2.3 EXPERIMENTAL ELECTROLYTE AND MACHINING PARAMETERS

Since chamber body 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 precision, 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 body cavity is gun barrel 40CrNi3MoV. 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, NaNO3+$NaClO_3$ solution is selected in this study for higher machining precision inner cavity with fillet. And selecting reasonable machining parameters (as Table 1) is significant to achieve higher machining precision and perfect surface quality except for proper electrolyte.

Table 1 Machining parameters

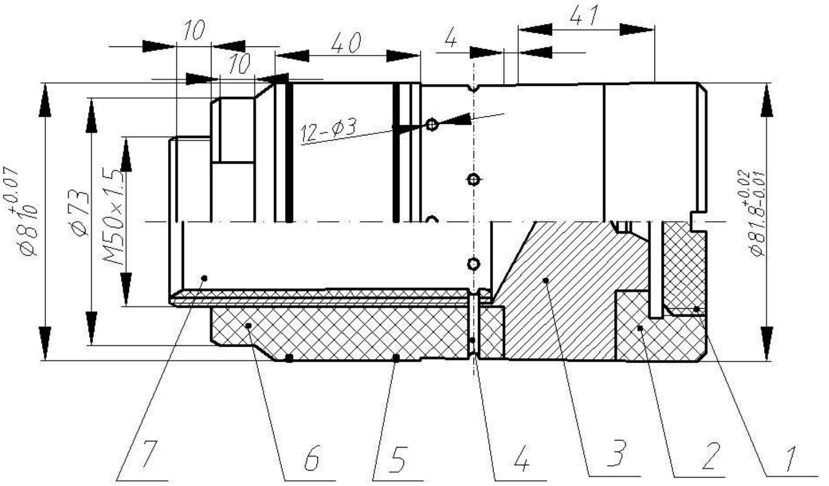
Machining parameters	Value
Machining voltage	17V
Electrolyte working pressure	1.5MPa
Feed rate	20mm/min
Initial gap	0.4mm
Electrolyte component and concentration	15%$NaNO_3$+5%$NaClO_3$
Electrolyte temperature	30~32□

2.4 EXPERIMENTAL CATHODE

2.4.1 Design on polished cathode in chamber body inner cavity: Mobile deep-hole ECM is applied to polish chamber body inner cavity with the cylindrical tool cathode (as Fig.4). 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) Cathode design and the calculation of processing current: Working part is the core in cathode body as the cutting edge in machining. The design of cathode working segment based on machining surface forming rules in the study is closely related to the determination of working current.

The diameter of workpiece preformed hole is set as D_1,the diameter of cylindrical cathode is D_c， $D_c = D_1 - 2\Delta$, and Δ is machining gap, when $\Delta = 0.5$ mm. The working length of cathode body is mainly determined by electric current density $i = \frac{I}{S}$, and then



1. Plug 2. After end guide sleeve 3. Cathode body 4. Feed liquid hole 5. Seal ring 6. Fore-end guide sleeve

Fig.4: The polished cathode of ECM for preformed hole of chamber body inner cavity

Table 2 Mobile deep-hole cathode of ECM

Name	Material	Function
Connector	Cooper	Connection and conduction
Fore-end guide sleeve	Epikote or acryl glass	To play a part of guide, location and insulation in the machining process matched with preformed hole
Seal ring	O-ring seal	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	Copper and or non-corrosive steel	To remove the metal as the cutting edge in the tool
After end guide sleeve	Epikote or acryl glass	To play a part of location and aerial drainage matched with the machined hole

$$i = \frac{I}{\pi D_C L_C} \tag{2.1}$$

$$L_c = \frac{I}{\pi D_C i} \tag{2.2}$$

$$S = \pi D_c L_c \tag{2.3}$$

S is the area of cathode working part, and L_c is its length. The total current density:

$$I = \frac{\pi h v}{2\eta\omega}(D + D_1) \qquad （2.4）$$

As follows: v is the feed rate in cathode axial direction（mm/min）, in general , v ranges between 15 and 25mm/min , v=25mm/min. ω is volume electrochemical equivalent, ω=2.2mm^3/A·min. η is current efficiency, 100% usually. D is the designed working diameter (after the polishing) in the blueprint.

Computed result: $D_1 = 81.2^{+0.07}_{-0.05}$ mm, $D = 82^{+0.09}$ mm, *h*=*D*-*D*$_1$=0.02mm, *S*=595.16cm^2, *I*=58.5A，L_C=2.3mm，L_C=4mm，*i* ranges between 10 and 25A/cm^2, *i*=10A/cm^2.

(2) The determination of Cathode feed liquid hole diameter and its location: The total cross section of feed liquid hole must be broader than the maximum wetted area between cathode and anode for sufficient supply of electrolyte, that is,

$$nS_2 \geq S_1 \qquad (2.5)$$

S_2 is sectional area of feed liquid hole, *n* refers to the amount of feed liquid hole, *D* is set as the machined part's aperture and *d* is the diameter of feed liquid hole, so

$$S_2 = \frac{\pi d_1^2}{4} \qquad (2.6)$$

$$S_1 = \frac{\pi(D^2 - D_c^2)}{4} \qquad (2.7)$$

$$n\frac{\pi d_1^2}{4} \geq \pi\frac{(D^2 - D_C^2)}{4} \qquad (2.8)$$

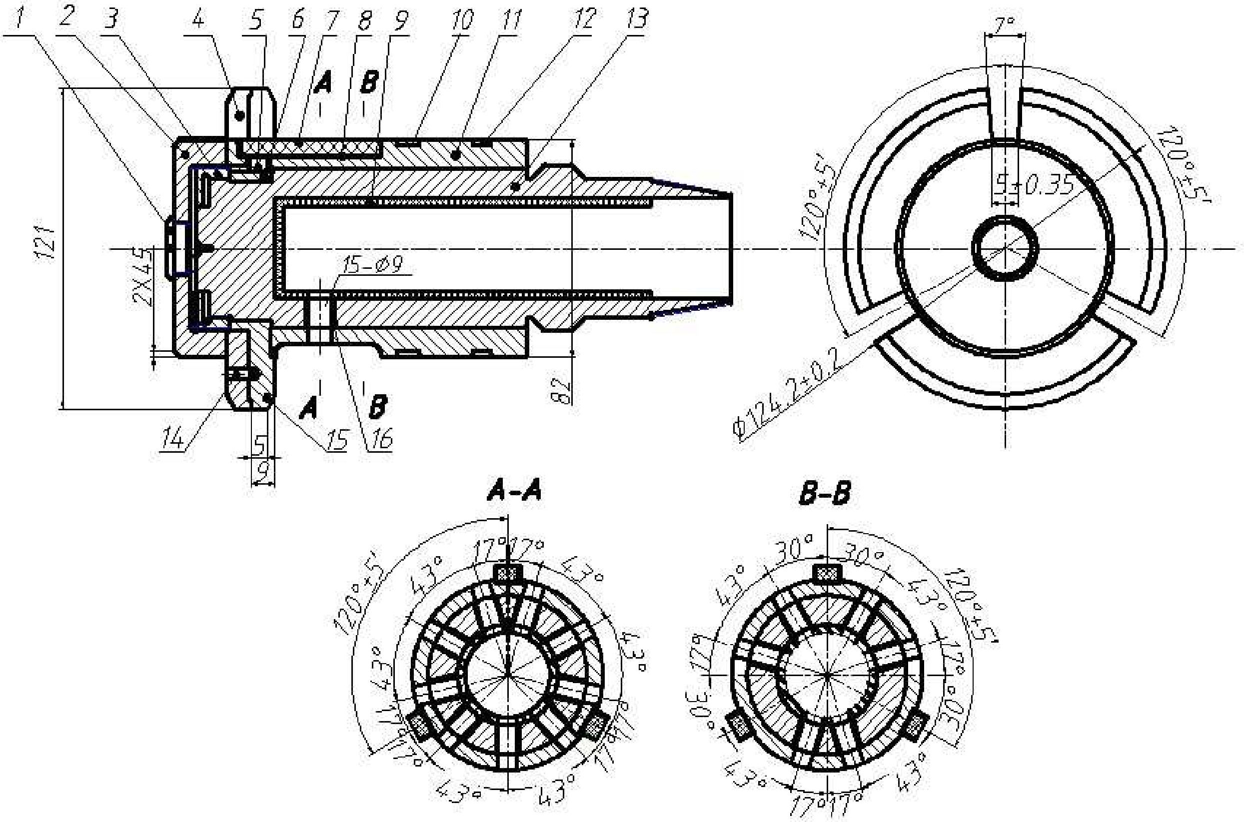
When practical aperture d_1 is more than the theoretical one, inner wall of feed liquid hole diameter must be insulated. Therefore, the determination of aperture should include the thickness of insulation.

$d_1 \geq \frac{\sqrt{D^2 - D_c^2}}{n}$ =0.25mm, when n=12, d_1 =0.25mm, d_1 =0.3mm.

(3) The determination of cathodic fore-end and after end guide sleeve: When selecting fit, coefficient of thermal expansion (CTE) of insulating material should be considered and try to use the insulating material with smaller CTE, correspondingly shortens the diameter of fore-end and after end guide sleeve. The distance of two adjacent seal rings in the cathode fore-end guide sleeve is determined to be 30mm for its usual distance ranges from 20mm to 50mm. The cathode fore-end guide sleeve can be selected a little longer and it is usually 40mm for the deep hole less than 70mm, thus, 40mm is selected in this design with the inner cavity of*Φ*82mm. After end guide sleeve can be shorter, ranging from 20mm to 30mm, and 20mm is determined. The former section of after end guide sleeve is guiding the fluid zone, with the same diameter as that of cathode.

The uneven electrolyte sprayed from feed liquid hole needs to be rectified, and the rectifying zone is located between feed liquid hole and working part in cathode body with the equal diameter. The length in rectifying zone is determined by the diameter of the working part in cathode body, the length accounts for 1/4-1/5 of the diameter, now 1/4 is selected, so DC ×1/4=20.25mm, and the dimension is 21mm. The diameter of seal ring isΦ82.1mm.

2.4.2 Design on cathode of chamber body inner cavity: According to the characteristics of inner structure in chamber body cavity, the design of tool cathode (as Fig.5 and Fig. 6) can be obtained based on equal gap method.



1. Plug 2. After end guide sleeve 3. Blocking disk 4. Insulation disk 5. Insulation piece 6.Fixed position key 7. Insulation sleeve 8. Rubber strip 9.Insulation sleeve 10. Seal ring 11.Fore-end guide sleeve 12. Seal ring 13. Cathode body 14. Stop pin 15. Cathodic disk 16. Cathodic plug

Fig.5 The Cathode of ECM for chamber body inner cavity

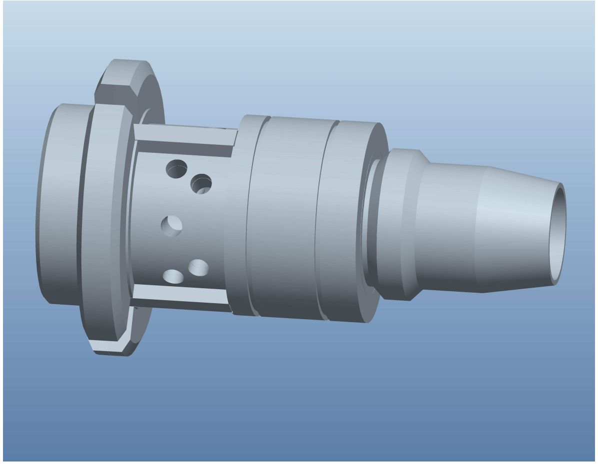


Fig.6 The graphic model cathode of ECM for chamber body inner cavity

Dimension parameter of cathode body feed liquid hole: The cathode diameter is D_c, the diameter of machined hole is D, feed liquid hole diameter is d_1. The electrolyte supplied by pump flows into machining zone from feed liquid hole of cathode body. For sufficient supply of electrolyte, the total cross section of feed liquid hole must be broader than the maximum wetted area between cathode and anode, according to the formula 2.9.

The determination of Cathode feed liquid hole diameter and its location: The total cross section of feed liquid hole must be broader than the broadest maximum wetted area between cathode and anode for sufficient supply of electrolyte, that is, $nS2 \geq S1$（2.9）, S_2 is sectional area of feed liquid hole, n refers to the amount of feed liquid hole, D is set as the machined part's aperture and d is the diameter of feed liquid hole, so

$$nS_2 \geq S_1 \tag{2.9}$$

As follows: S_2 *is the* sectional area of feed liquid hole. S_1 is the section of largest discharge area. The n is the number of feed liquid hole. The diameter of machined hole is D. The diameter of feed liquid hole is *d*. d_1=9mm, according to 2.10 and 2.11, S_2 is sectional area of feed liquid hole, S_1 is the maximum a between cathode and anode.

$$S_1 = \frac{\pi(D^2 - {D_C}^2)}{4} \tag{2.10}$$

$$S_2 = \frac{\pi {d_1}^2}{4} \tag{2.11}$$

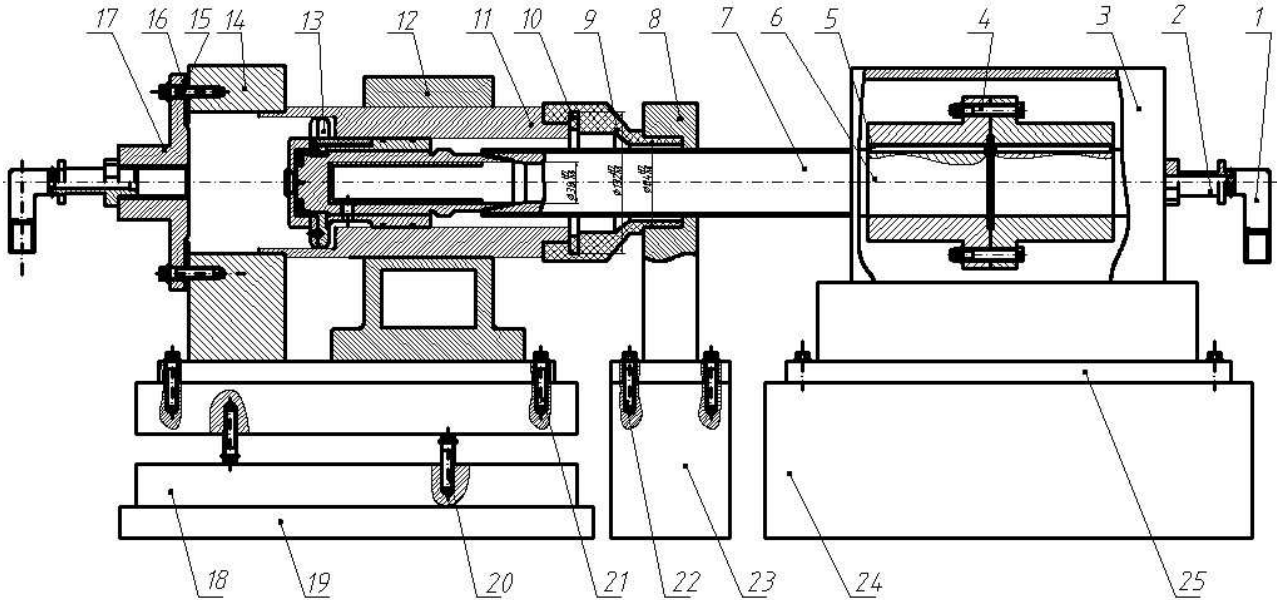
$S_2 = 63.59\ \text{mm}^2$, $S_1 = 941.31\ \text{mm}^2$. According to the formula 2.8, so $n = 15$。The position of feed liquid hole is located between fore-end guide sleeve and cathode body. The distance of two seal rings on the fore-end guide sleeve is 20mm. The length of fore-end guide sleeve for *Φ*82mm of chamber body inner cavity of preformed hole. The after guide sleeve is 20mm. The diameter of seal ring is *Φ*82mm.

2.5 THE DEVICE OF ECM FOR CHAMBER BODY CAVITY

2.5.1 Design on ECM device of chamber body cavity: 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 (as Fig.8 and Fig.9) and fixture 12(as Fig.10 and Fig.11) can realize the insulation with workbench.

2.5.2 Design on ECM fixture of chamber body cavity: 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 conductive.

The fixture 14 (as Fig.8 and Fig.9) is shown in Fig.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. The fixture is fixed on the workbench of the machine tool through the bolt connection.



1. Elbow pipe joint 2. Pipe joint 3. Spindle box 4. Bolt 5. Coupling 6. key 7. Draw bar 8. Fixture body 9. Seal cartridge 10. Seal gasket 11. Chamber body 12. Fixture body 13. Cathode 14. Fixture body 15.Seal 16. Bolt 17. Flange plate 18. Current-conducting plate 19. Workbench 20. Bolt 22. Bolt 23. Workbench 24. Workbench 25. Insulating plate

Fig.7: The device of ECM for Chamber body inner cavity

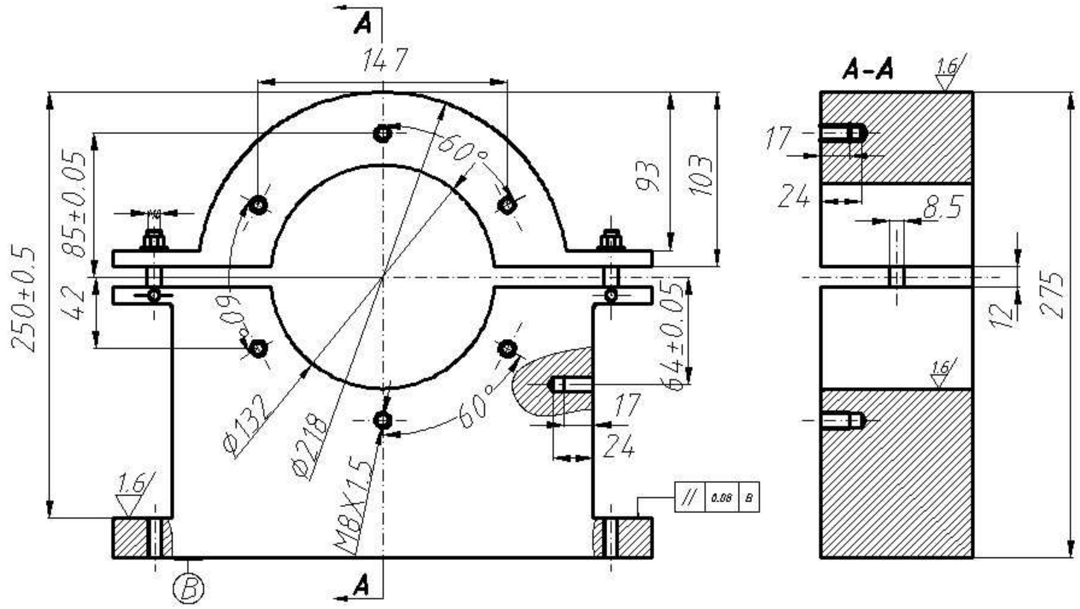


Fig.8: The fixture of ECM for chamber body inner cavity

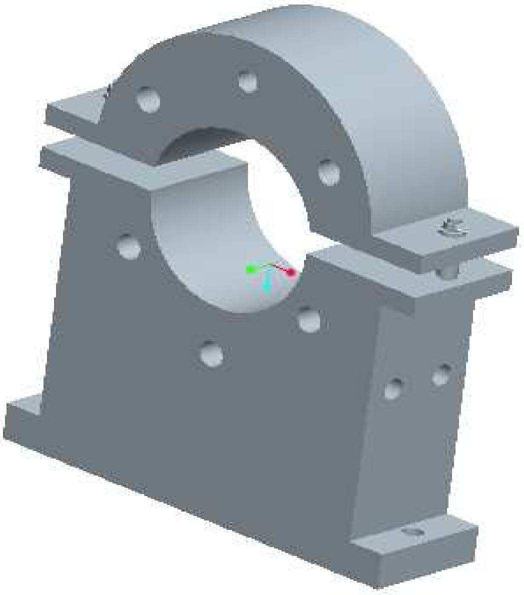


Fig.9: The fixture graphic model of ECM for chamber body inner cavity

One side is revolute fixture 12 (as Fig.10 and Fig.11), 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 hole 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.

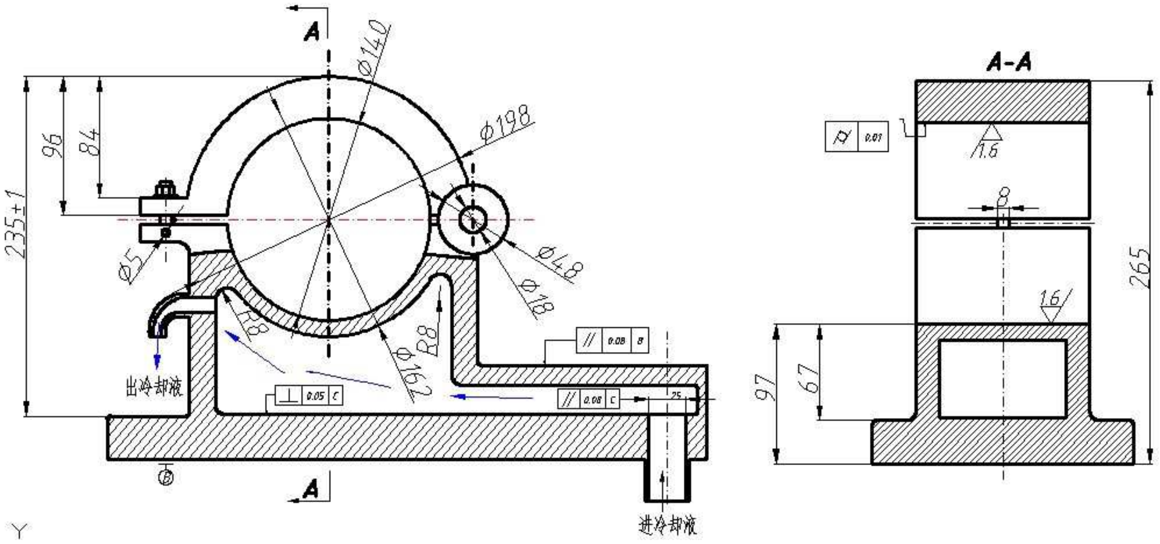


Fig.10: The fixture of ECM for chamber body inner cavity

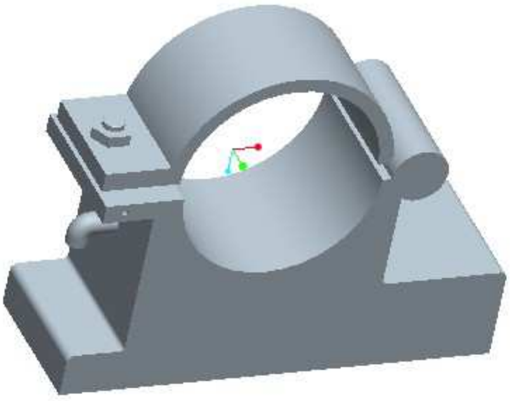


Fig.11: The Fixture graphic model of ECM for chamber body inner cavity

The sample piece of chamber body inner cavity machined in ECM and it is cut by Wire Electrical Discharge Machining (WEDM) into thin slices of 0.8mm thick as Fig.12.

Fig.12: The sample piece of ECM for chamber body inner cavity

CONCLUSION

A high efficiency ECM method and device of chamber body inner cavity is presented in this paper. The results implies that this device of ECM device realizes high efficiency, low cost, no cutting stress and inner cavity primary shaping, and the machined chamber body inner cavity workpiece coincides well with the blueprint and obtains notable economic benefit. Total precision of chamber body inner cavity ranges from ±0.03mm to ±0.11mm, and surface smoothness ranges from Ra0.8μm to 0.4μm, its precision is similar to copy milling that is inferior to EDM, while surface smoothness is superior to copy milling and EDM.

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REFERENCES

[1] AR Mount; PS Howarth;D Clifton. *J. Appl. Electrochem*, **2001,** 31(11), **1213-1220.**
[2] KP Rajurkar; D Zhu; JA; McGeough; J Kozak; A De Silva. *CIRP Annals* , **1999,**48(2), **567-579.**
[3] MS Hewidey; SJ Ebeid; KP ajurkar; MF El-Safti. *J. Mater. Process. Technol*, **2001,**140**(1-3)**, **287-291.**
[4] NS Qu; XL Fang; W Li; YB Zeng; D Zhu. *CHINESE. J. ERONAUT*, **2013,** 26**(1)**. **224-229.**
[5] C Senthilkumar; G Ganesan; R Karthikeyan. *INT. J. ADV. MANUF. TECH*, **2009,**43**(3-4)**. **256-263.**
[6] VK Jain; PC Pandey. *Precis. Eng*, **1980,** 2**(4)**, **195-206.**
[7] PT Pajak; AKM De Silva; JA McGeough; DK Harrison. *J. MATER. PROCESS. TECH.*, **2004,**149**(1-3), 512-518**
[8] ZJ Fan; TC Wang. *Electromachining & Mould*, **2000,** 4**(20)**, **24-28**.
[9] T Haisch; E Mittemeijer; JW Schultze. *Electrochim Acta*. **2001,**47(1-2). **235-241.**
[10] JA McGeough. Principle of Electrochemical Machining, 1st Edition, Chapman& Hall, London, **1974**; 75-79.
[11] B. Bhattacharyya; B Doloi; PS Sridhar. J.*Mater. Process. Technol.*, **2001, 113(1-3)**. **301-305**
[12] J Shen; HY Zhang. *Electromachining & Mould*, **2001,** 4**(45)**, **21-26.**
[13] ZJ Fan; TCWang. Technology and Research Method of Electrochemical Machining, 1st Edition, National Defence Industry Press, Beijing, **2004;89-95.**
[14] QT Jin. Non-traditional machining, 1st Edition, Aviation Industry Press, Beijing, **1988**; 56-61
[15] VD Kashcheev; NS Merkulova; AD Davydov. *Applied electrical phenomena*, **1966, 5(5)**, **207-214.**
[16] ZKYao. Forging Technology and Die Design, 2ed Edition, Northwestern Polytechnical University Press, Xi’an, **1998; 67-76.**
[17] M Datta; D Landolt. *Electrochim. Acta*, **1981,**26**(7)**, **899-907.**
[18] KP Rajurkr; SC Tam. *J. Mater. Process. Technol*, **1992,**35**(6)**, **83-91.**
[19] JY Wang; JW Xu. ECM Processing Technic Used for Mold Cavity, 1st Edition, Peking University Press, Beijing, **2001; 93-98.**
[20] TC Wang. *Electronmachining*. **1983,1(10). 16-20.**
[21] OH Narayanan; S Hinduja; CF Noble. *Journal of Mechanical Engineering Science*, **1986,**200**(3), 195-205.**