ELECTROCHEMICAL MACHINING OF OIL GROOVED BUSHINGS

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ABSTRACT

Bushings (sleeves) with oil grooves are parts made of high hardness material (52 - 60HRC) and work in high pressure environments. The oil grooves are specially designed coolant channels on the inner cylindrical surface of the bushings to provide lubrication and cooling for the mechanical members. Currently, in order to machine these grooves in holes, mechanical cutting methods such as: turning, broaching, slotting... can commonly used. The disadvantages of these conventional methods are low productivity, low accuracy and the product quality depend heavily on worker skills. In this study, electrochemical machining method is used to machine oil grooves to achieve a high productivity and quality with a reasonable cost. This article presents the calculation and experimental selection of main parameters when designing and manufacturing electrochemical cathodes. Through calculations and experiments, based on existing equipment conditions, the article has determined a reasonable set of technological parameters for machining oil grooves: electrode gap $\delta = 1$mm; flow pressure P = 6at; NaCl 11%; machining time t = 125s and $I_m = 70$A.

Keywords: *Advanced machining processes; Electrochemical Machining; Bushings; Cathode tool; Oil grooves.*

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1. INTRODUCTION

The bushings, used to guide and properly locate drills, reamers etc. are generally made of alloy steel and made wear resistive by hardening to 50HRC and above. The hardened jig bushings are finished outside by grinding and inside by grinding and lapping if high precision is insisted. In many practical applications, bushings with oil grooves are used for supporting steadily loaded rotating shafts. When shaft speed and specific load are high, oil viscous shearing generates a significant amount of heat and, as a consequence, high operating temperatures may be expected.

Currently, the traditional machining sequence used to cut bushings is as follows [1]:

1. Workpiece preparation.
2. Machining the main surfaces (front surface, outer cylindrical surface, drilling holes).
3. Drill additional holes (oil holes).
4. Machining shaped surfaces (keyway, oil groove).
5. Heat treatment.
6. Finishing the surfaces.

In general, there are many different types of grooves such as: straight grooves, elliptical grooves, spiral grooves, 8-shaped grooves [2]. The most commonly used cross sectioned groove profile is the rectangular groove profile shown in Fig. 1a. However, when an abrupt enlargement of section occurs in a passage, a rapid deceleration takes place accompanied by characteristic large-scale turbulence, as shown in the figure, which causes significant losses in the downstream pressure. In order to avoid such effects and improve the performance of bushings, it is found that a circular groove profile shown in Figure 1b has better stability characteristics than the rectangular groove profile [3]. These stability characteristics are greatly affected the bushing especially at concentric operation and the load capacity of the bushing approached an asymptotic value with increasing speed.

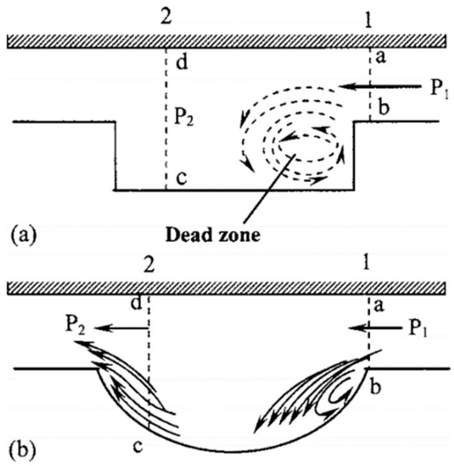
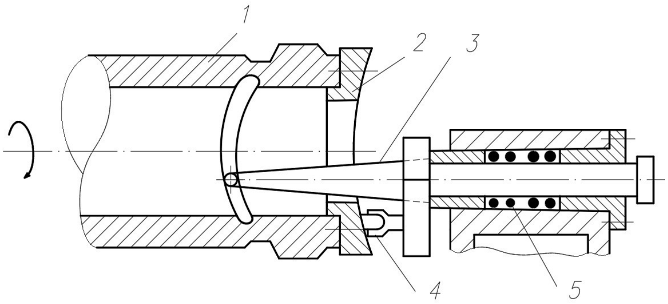


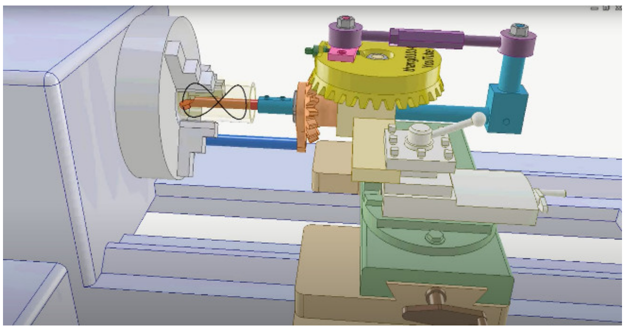
Fig. 1. Lubricant flow over the groove: (a) Rectangular groove profile; (b) Circular groove profile

Currently, most of researches and manufacturing processes of oil-grooved bushings are limited to traditional machining methods such as turning, broaching, slotting on universal machines or milling on CNC machines. According to one example, the oil grooves can be manufactured by turning method using copying template (Fig. 2a) or using specialized jig (Fig. 2b). The principle of copy turning process is depicted in Fig. 2a, in which workpiece 1 and copying template 2 are mounted coaxially and synchronously rotated by the worm gears system. Roller 4, with the help of spring 5, againsts on the cam surface of copying template 2, thereby cutting tool 3 can cut the desired groove. On the one hand, the disadvantages of these traditional cutting methods are low productivity, low accuracy, and product quality depends mainly on worker skills. On the other hand, in practice, it is difficult to form the desired cross sectional profile of groove on hard material by using conventional cutting tool as shown in Fig. 3.



1. Workpiece; 2. Copying template; 3. Cutting tool; 4. Roller; 5. Spring

(a)



(b)

Fig. 2. A schematic diagram of oil-groove turning process

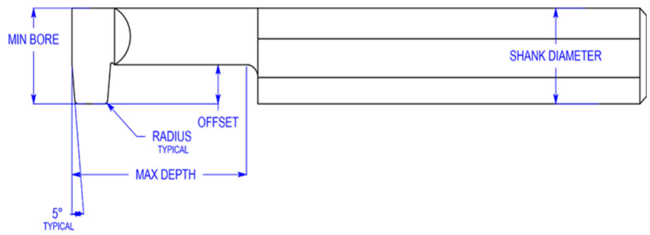


Fig. 3. Geometry of traditional turning tool

Electrochemical machining (ECM) is an advanced machining process with many outstanding advantages. This process can easily cut hard materials with high productivity and accuracy and does not create any burrs. In 1974, McGeough [4] studied the principles of ECM and determined the influence of technological factors (electric current, electrolyte, electrode material) on material removal rate. Z. Pandilov et al. [5] researched the application of ECM in machining difficult-to-cut materials such as titanium-based alloys and nickel-based alloys and determined the optimal set of parameters for ECM machining under harsh conditions (high temperature, high load, high friction and high wear) in the fields of energy, transportation, and machine manufacturing. In military industry, ECM is the best candidate for manufacturing gun tube rifling. V.D. Nguyen et al. built an ECM system for machining different types of barrels [6]. Do T.L et al. calculated and designed a cathode to produce rifling on the inner surface of the naval 30 mm cannon barrel [7].

Although many research institutes and scholars have already initiated some researches using parameters optimization to improve ECM performance in gun tube rifling machining, but there is no researches on applying ECM to process oil grooves in high hardness bushings. Therefore, if applied to bushing machining process, it is possible to shorten the traditional process planning by omitting the heat treatment step and solve the problem of productivity and quality in machining oil grooves. The cost of making cathode is 5 to 10 times cheaper than mechanical cutting tools. Its productivity is much higher than mechanical processing, too. For these reasons, this research is carried out to apply ECM process for manufacturing the oil grooves to achieve high quality (machining precision, good surface and no burrs) and high productivity by machining 6 parts simultanously.

2. MATERIALS AND METHODS

2.1. Oil-grooved bushing

The busing is made from 40X steel that has been heat-treated to achieve a hardness of 52 - 60HRC as described in Table 1. Its chemical composition (weight percent) and mechanical properties shown in Table 1.

Table 1. Chemical composition and mechanical properties of 40X steel bushing [8]

C (%)	Si (%)	Mn (%)	Cr (%)	Ni (%)	P (%)	S (%)	Cu (%)	Hardness (HRC)
0,38-0,43	0,15-1,35	0,65-0,85	0,9-1,20	-	<0,03	<0,03	-	58

There are 4 grooves need to be processed inside the bushing including 3 longitudal straight grooves and 1 horizontal groove. Dimensions of the 3 longitudal grooves are $1.1^{+0.2}$mm in depth, $3^{+0.12}$mm in width, 46mm in length. The structure sketch of bushing is as shown in Fig. 4. The oil inlet holes should be chamfered and have all edges rounded and broken to form unrestricted entrances for the lubricant to enter. All grooves should be blended and rounded to reduce the effects of sharp edges that interfere and scrape the lubricant and prevent the formation of an oil film. The oil flow of a bushing with a circular groove is about 2.5 times that of a bushing with an oil hole only.

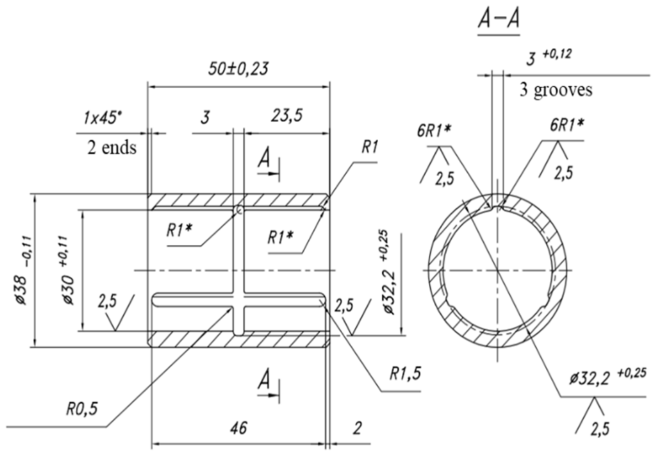


Fig. 4. Blueprint of a desired bushing

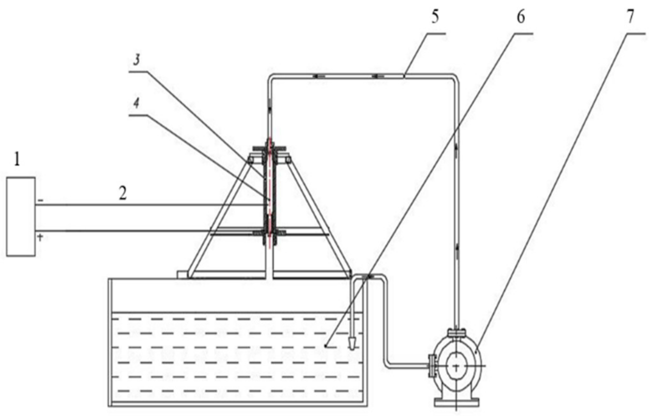
2.2. Experiments and measurements

Based on the machining equipments existing at the factory, a planning process was established as shown in Table 2.

Table 2. The process planning of oil-grooved bushing

Operation number	Routing sheet
1	Preparing the billet (Φ40mm x 310mm)
2	Facing, hole drilling Φ25mm and parting off L = 305±0.1
3	Boring Φ27mm; Φ29mm
4	Finishing turning Φ39
5	Heat treatment
6	Grinding
7	Reaming $\Phi30^{+0.11}$
8	Electrochemical machining oil grooves $\Phi32.2^{+0.25}$
9	Inspection

In operation 8, the experiment was conducted on an ECM system with the basic configuration indicated in Fig. 5. Key parameters of the ECM system are summarized in Table 3.



1- Power unit; 2- Electric cables; 3- Workpiece; 4- Cathode; 5- Electrolyte tank; 6- Pipe system; 7- Pump.

(a) A schematic diagram of ECM system

(b) Pump

(c) Power supply unit and PLC controller

(d) Electrolyte tank

Fig. 5. Basic configuration of the ECM system

Table 3. Key parameters of the ECM system

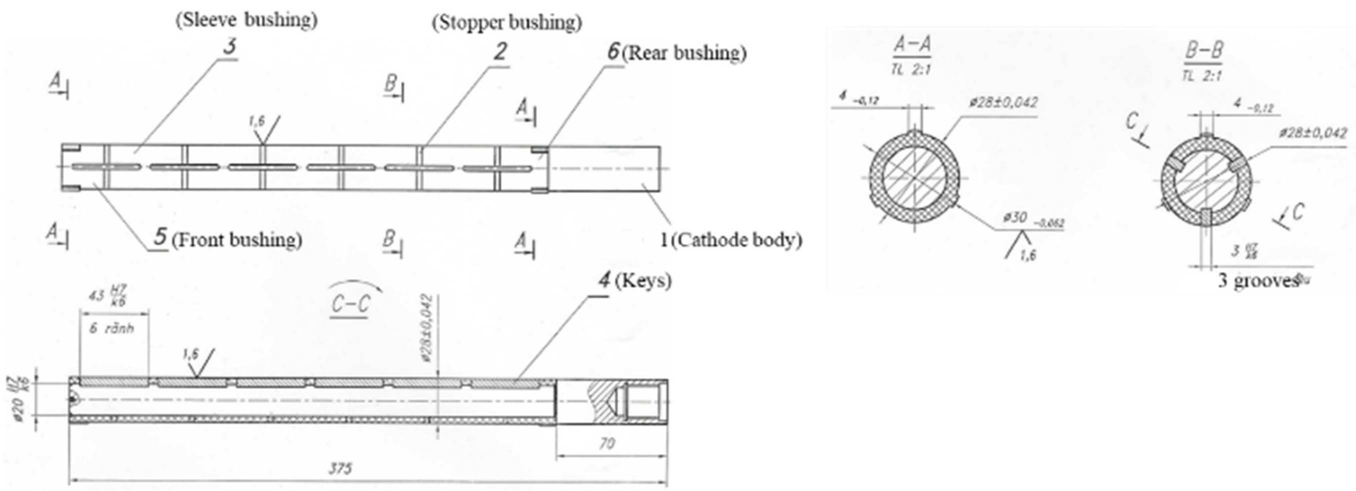
No.	Parameters	Value
1	Power supply system	I = 0 ÷ 400A U = 0 ÷ 24V
2	Pump pressure	≥ 25at
3	Flow rate	≥ 6m^3/h
4	Electrolyte tank	2m^3
5	Cathode, fixtures	
6	Electrolyte temperature	20 ÷ 35°C

Digital camera (Model: Samsung Note 9, Korea) and microscope were utilized to capture and analyze the grooves. Meanwhile, the surface roughness tester TR200 (Mitutoyo Corp.) with a resolution of 0.01µm was used to measure the surface roughness of the grooves.

3. TOOL APPURTENANCE DESIGN AND MANUFACTURING

3.1. Cathode

In order to increase the machining capacity and accuracy, cathode was designed to cut 6 workpieces at the same time. Here, cathode was made from brass, while insulating parts were made of ebonite.



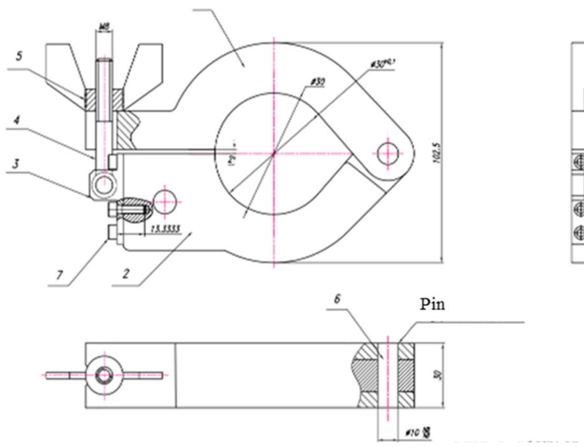
(a) Sketch of designed cathode

(b) Real cathode

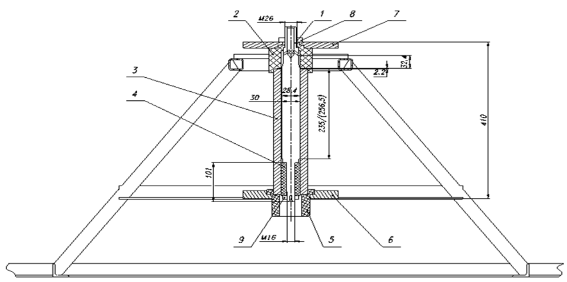
Fig. 6. Cathode design

3.2. Jigs and fixtures

During the electrochemical machining process, it is necessary to pay attention to the stability of the equipment and avoid the vibration of the equipment, so that a fixture should be designed to be fix and locate the workpiece such that a small gap between tool and workpiece is maintained.



(a) Clamping unit



(b) Jig and fixture

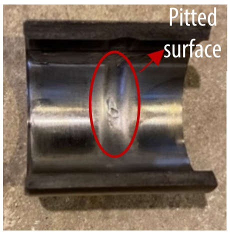
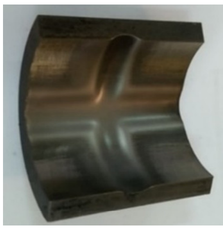
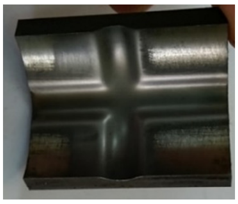
1- Cathode; 2- Upper flange; 3- Workpiece; 4- Guide flange; 5- Lower flange; 6- Lower body; 7- Upper body; 8- Nut M26; 9- Nut M16.

(c) Real jig and fixture

Fig. 7. Jig and fixture design

4. RESULTS AND DISCUSSION

Because electrochemical processing technology has many parameters that affect the quality of the product, we choose the segmentation option. Current density I_m is the most important parameter and can be adjusted through the input voltage U_o, so the author decided to study its influence on the quality and speed of groove corrosion. Based on the previous study of T.L Do et al. [7], other parameters were fixed as follow: Electrode gap δ = 1mm; Flow pressure P = 6at; and electrolyte concentration (NaCl 11%).

No.	I_m (A)	Time (s)	Groove dimension and quality		Remark
1	90	80	- Depth: 0.2mm - Width: 2.5mm - Corner: R1.5mm - R_z = 3.2µm		The groove has been created, but its shape is not clear and its surface may be passivated
2	75	100	- Depth: 0.93mm - Width: 2.9mm - Corner: R1.3mm - R_z = 2.5µm		The groove has been machined with good surface quality, but its dimensions are not correct.
3	70	125	- Depth: 1.12mm - Width: 3mm - Corner: R1.05mm - R_z = 2.5µm		Qualified

By using the static cathode, it is possible to machine grooves of a bushing that meets technical requirements. After several times of experiments, to ensure the elimination of passivation of the anode's working surface, the following optimum technological parameters can be applied: electrode gap δ = 1mm; flow pressure P = 6at; NaCl 11%; t = 125s; and I_m = 70A.

5. CONCLUSION

ECM was performed on oil-grooved bushings. The conclusions of this research can be listed as follows:

1. Design the process planning of oil-grooved bushing.

2. Design the static cathode for machining 6 parts at the same time.

3. Design jigs and fixtures to maintain electrode gap during ECM.

4. Research the influence of current density on machining quality of grooves. The current pulse I_m = 70A, electrode gap δ = 1mm, flow pressure P = 6at, machining time t = 125s, and NaCl 11% are good for groove machining.

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