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Electro-Chemical Machining

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Abstract **- Electrochemical Machining is a non-traditional machining process which is used to machine difficult-to-machine materials such as super alloys, Ti-alloys, stainless steel etc. The basic working principle is based on Faraday law of electrolysis due to which the material removal takes place atom by atom by the process of electrolysis. Electro-Chemical Machining (ECM) is the generic term for a variety of electrochemical processes. ECM is used to machine work pieces from metal and metal alloys irrespective of their hardness, strength or thermal properties, through the anodic construction, medical equipment, micro-systems and power supply industries. The Electro Chemical Machining is extremely suitable for machining of materials used in extreme conditions. General overview of the Electro-Chemical Machining and its application for different materials used in extreme conditions is presented. Jet electrochemical machining (JECM) process can be used to machine conductive materials but there is a stray machining effect which leads to reduce the effectiveness of machining. To eliminate this problem, a hybrid laser-assisted jet electrochemical machine (LA-JECM) has been fabricated and utilized for experimental investigation.**

Keywords: Electro chemical Machining, Non-Traditional Machining, Machining Effect.

I. INTRODUCTION

Electro Chemical Machining, abbreviated ECM, is an advanced metal-working technique which can machine products that are difficult or impossible to design through conventional machining. It is an extremely accurate technique, capable of machining any electrically conductive work piece due to the fact that the technology is based on electrolysis (i.e., chemical change, especially decomposition, produced in an electrolyte by an electric current). ECM is used in aerospace, automotive, construction, medical equipment, micro-systems and power supply industries. Almost all kinds of metal can be electro-chemically machined, especially high-alloyed nickel - or titanium-based ones, as well as hardened materials. As it is a contactless procedure with no heat input, the process is not subject to any of the disadvantages experienced with traditional machining methods, e.g. tool wear, mechanical stresses, micro-fissures caused by heat transfer or the need for subsequent deburring operations. All electrochemical machining processes are characterized by stress-free stock removal, gentle transitions and top-quality surfaces without burr formation. During the process the metal work piece is dissolved (Machining) locally through electricity (Electro) and chemistry (Chemical) until it reaches the required complex 3D end shape. The Electrochemical Machining process (ECM) can be applied for shaping advanced conductive materials which are difficult or impossible for machining using conventional methods. In electrochemical machining the workpiece is an anode and material is removed as a result of electrochemical reactions. This mechanism of material removal makes it possible to obtain high metal removal rate and good surface layer quality when machining parts made of super-alloys, alloys, steels and some composite materials on metallic base.

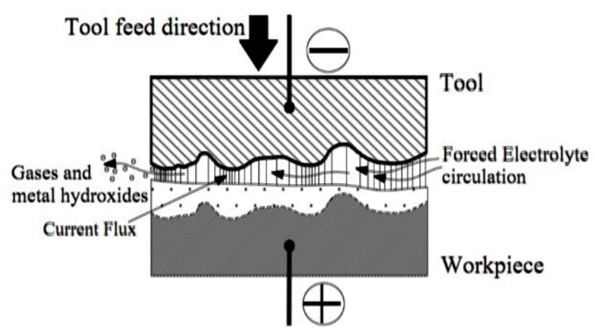

Figure 1: Basic Scheme of ECM

ECM process mathematical modeling because the phenomena occurring into inter electrode gap are very complicated. In order to simplify the mathematical modeling it is necessary to introduce some modification of the ECM sinking process by: application of pulse voltage (Pulse ECM) often correlated with electrodes vibration, ECM machining with universal electrodes. The other important directions of ECM process development are: manufacturing processes by electrochemical deposition and some hybrid processes as electrochemical-electro discharge or electrochemical grinding machining.

ECM plays an important role in manufacturing of a variety of parts ranging from machining of complicated shape, complex, and large metallic pieces.

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- Faraday's: ECM, Electroplating, Electro polishing based on the concept of Faraday's Laws.
- ECM: ECM is based on electrolysis where material is removed from workpiece surface atom by atom.
- Parameters: Input parameters: Supplied voltage, machining current, electrolyte type, concentration, flow rate and inter-electrode gap Output parameters: Metal removal rate, surface finish and profile accuracy.

Electro chemical machining
Miniaturization:

- It is the need of the time.
- Medical, µ-tools, Mobiles, Mini robots, Bio-medical implants, utensils etc.

Advanced micromachining:

- Consists the application of various ultra-precision processes applied to make micro-sized holes, slots and micro complex surfaces that are needed in large numbers.

Limitations of traditional machining:

- High tool wear, lack of rigidity of the process and heat generation at the tool-workpiece interface.
- It is troublesome to machine three dimensional micro-shapes.
- Some important points about the ECM process.
- In electrolytes, the atoms or group of atoms carries the current and not by the electrons as in the case of conductors, when the electrons move and as a result, we get current.
- The atoms have acquired positive or negative charges by either lost or gained electrons and such atoms are called ions.
- The ions that carry positive charge are attracted by the cathode and they move in the direction of the positive current through electrolyte and are referred to as cations. The negatively charged ions get attracted to the positive electrode i.e. the anode and they are referred to as the anions.

II. COMPONENTS OF ELECTRO CHEMICAL MACHINING EQUIPMENT

ECM equipment is completely tool oriented. The tooling has to be decided first, and then the proper machine for use must be selected. However, the feed drive systems, work enclosure systems remain same for all machine types. Industrial Electro Chemical Machining equipment consists of the following 4 systems (components):

DC Power supply: The machining rate in electrochemical machining is proportional to the electric current density. In order to achieve high values of the machining rate electrochemical machining is commonly performed at a high direct current exceeding 1000.

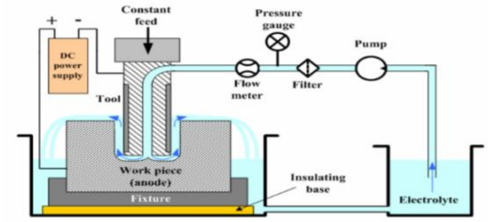

Figure 2: Components of Electro chemical machining Equipment

The gap between the tool and the work piece must be low for high-pitched correctness, thus the voltage must be small to prevent a short circuit. The voltage of the process is 5-25 V. The control system uses some of this electrical power.

Electrolyte circulation system: The products of the electrochemical reaction should be removed from the gap between the work piece and the tool. Accumulation of the reaction products causes decrease of the process efficiency and reduction of the rate of machining. Therefore, the electrolyte flow speed should be high. Commonly it is in the range 300-3,000 m/min (1,000-10,000 ft/min). The inlet pressure should be in between 0.15-3 MPa. The electrolyte system should comprise a fairly strong pump. The electrolyte is continuously filtered in order to trap the precipitated reaction products (sludge).

Control system: Electrical parameters of the process (voltage and current)), tool feed speed and parameters of electrolyte circulation system (inlet and outlet pressure of electrolyte, temperature of electrolyte) are controlled by the control system, which provide stable and efficient operation of the unit

Mechanical system: It consists of the table, the frame, work enclosure (prevents the electrolyte from spilling), the work head (where the tool is mounted). The tools (electrodes) are also part of the mechanical system. One of the most important parameters of electrochemical machining is maintaining a constant voltage level. This is achieved by the control system providing a movement of the tool at a constant speed equal to the linear rate of machining. The process in a steady state is performed at a constant (typically gap 0.1-0.4 mm / 0.004-0.016"). A firm fixation of the work piece provided by the fixture, the table and the frame is also important for stable operation of the system at a constant gap. Conventional machining equipment including CNC machines may be modified for electrochemical machining process.

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2.1 The principle used is electrolysis

Basically, electrolysis is used for electroplating for conducting materials. Electrolysis is a chemical process, which occurs when an electric current is passed between two conductors dipped into a liquid solution. The conductor connected to positive terminal is referred as anode and another connected to negative terminal is called as cathode. The system of electrodes and electrolyte is referred as electrolytic cell, whilst the chemical reactions, which occur at the electrodes, are called as the anodic or cathodic reactions. The reaction is completed when the anode is completely eaten away. When the electrodes are weighted at the end of electrolysis, the anodic electrode will be found to have lost weight, whilst the cathodic electrode gains the weight by an amount equal to the lost by other electrode.

The electrolysis of an aqueous solution of copper sulphate using copper electrodes results in transfer of copper metal from the anode to the cathode during electrolysis.

$$CuSO_4 \implies Cu\ (++)\ +\ SO_4\ (--)$$

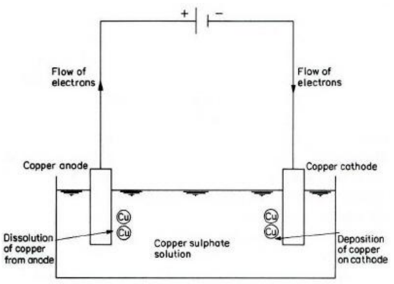

Figure 3: Electrolysis of copper sulphate solution

2.2 Need for ECM

Hard and difficult-to-shape metals cannot be easily machined by conventional machining methods. Also, a few of the non-traditional methods, although can be used on these materials, they are not suitable for mass production. In such cases, ECM becomes a choice.

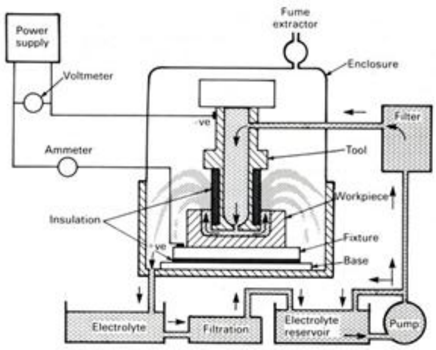

Figure 4: Experimental setup

2.3 About Experimental Setup

Mechanical system: It consists of the table, the frame, work enclosure (prevents the electrolyte from spilling), the work head (where the tool is mounted). The tools (electrodes) are also part of the mechanical system. One of the most important parameters of electrochemical machining is maintaining a constant voltage level. This is achieved by the control system providing a movement of the tool at a constant speed equal to the linear rate of machining. The process in a steady state is performed at a constant. A firm fixation of the work piece provided by the fixture, the table and the frame is also important for stable operation of the system at a constant gap. Conventional machining equipment including CNC machines may be modified for electrochemical machining process.

2.4 About the Tooling

The tool also called the electrode forms the negative terminal of the circuit. The shape of the tool must be similar to the shape desired in the workpiece. Since small gap has to be left between tool and workpiece for the electrolyte to flow, the tool is made smaller in size than that of size required in workpiece.

The material selected for the tool must be easily Machine-able, exhibit good stiffness to resist high electrolyte pressure and chemical action of the electrolyte, and a good electric and thermal conductor. The periphery of the tool must be well insulated to prevent machining action on its sides by the electrolyte flow around the tool. Also, a small hole is drilled in the tool for electrolyte to flow to the cutting zone.

2.5 About Electrolyte

The main function of the electrolyte is to complete the electric circuit between the tool and the workpiece and at as conductor to carry current. It removes the products of electro machining from the gap between tool-work interfaces. Carry the heat generated from the machining zone

They possess high electric conductivity, low viscosity and they are non-toxic an non-corrosive, inexpensive and easily available, high specific heat and chemically stable. Perfect electrolyte flow across the machining tool is mandatory for proper machining. Cavitations are likely to be occurred in the tool. So proper care is necessary to keep the tool in shape. Tool design must ensure the uniform flow of electrolytic solution in all machining areas. Optimum flow of the electrolyte is desired because excessive flow can cause erosion of the tool.

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2.6 About Power Supply

The AC power supply is converted into low voltage DC current with a step down transformer and a rectifier. Current of the order 1000-40000 A is required for machining, while the voltage ranges from 2-25 V.

The power supply also includes a protective device for OFF in the event of tool getting too close to the workpiece, or failure of electrolyte supply, or supply of improperly filtered electrolyte.

2.7 About Filters used for Electrolyte

Filters are placed in the system to clean the contaminated electrolyte, so that a fresh flow of electrolyte to the machining area takes place all the time. A wire mesh of 75µm size is made from Monel metal is commonly used.

Since the filters get clogged with small particles of grit and products of machining, they need to be cleaned once in 30 hours. Alternately, a centrifuge separator can be used for the purpose.

III. WORKING PIRNCIPLE OF ELECTRO CHEMICAL MACHINING

Electrochemical machining is based on the principle in which the workpiece and tools is the anode and cathode respectively, of the electrolytic cell, and a potential difference, usually at about 10 V, is applied across them. A suitable electrolyte, for example aqueous sodium chloride solution is chosen so that the cathode shape remains unchanged during electrolysis.

The electrolyte is pumped at a rate 3 to 30 m/sec through the gap between electrodes to remove the products of machining and to diminish unwanted effects, such as those that arise with cathodic gas generation and electric heating.

The rate at which metal is then removed from the anode is approximately in inverse proportion to the distance between the electrodes. As machining proceeds, and with the simultaneous movement of the cathode at a typical rate, for example, 0.02 mm/sec towards the anode, the gap width along the electrode length will gradually tend to a steady-state value. Under these conditions, a shape, roughly complementary to that of cathode, will be produced on the anode. A typical gap width then should be about 0.4 mm.

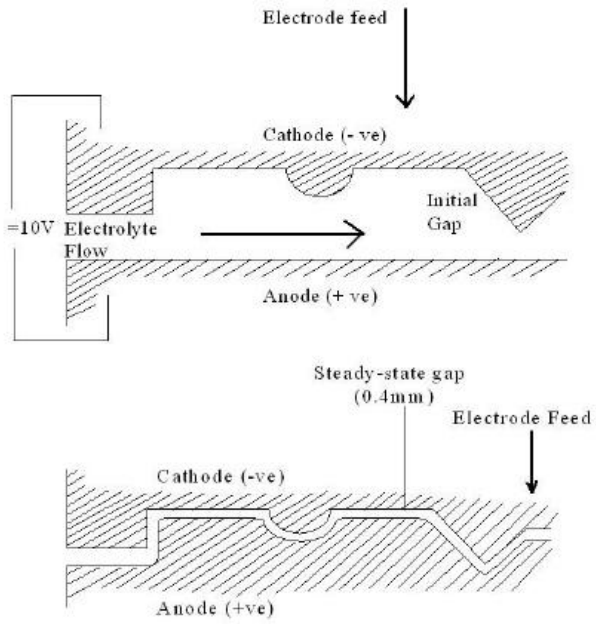

Figure 5: Electro chemical machining

3.1 Applications of Electrochemical Machining

Electro Chemical Machining is mainly used in the areas where conventional machining techniques are not feasible. Theoretically Electro Chemical Machining could be used for machining the all electro conductive metals and alloys.

3.2 Some of the Applications

- Machining of cavities in forging dies, drilling deeper holes and irregular shaped holes which cannot be obtained by conventional machining methods.
- Machining of complex profiles like turbine wheels, turbine and jet blades.
- Die sinking: Electro Chemical Machining is often used as an alternative to the cavity type electric discharge machining (EDM).
- Fabrication of thin walled parts: Electrochemical machining does not produce surface stress in the work piece therefore even very brittle and easily deformed materials may be machined in thin walled shapes.
- Grinding of a work piece by a rotating wheel, which performs grinding operation through an electrolyte. The wheel is conductive and catholically connected. Non-conductive hard particles are set on the wheel surface. The particles provide a constant gap through which an electrolyte is continuously fed. Hard and brittle materials are ground by the method.
- Rough corners or edges can be turned into very smooth parts and the process is known as deburring.

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IV. ELECTROLYTE AND ITS CONCENTRATION

The electrolyte solution is essential for the electrolysis process to work. An electrolyte in ECM performs three basic functions, which are as follows:

1) Completing the electrical circuit and allowing the large current to pass.
2) Sustaining the required electrochemical reactions.
3) Takes away the heat generated and the sludge.

Electrical conductivity of the electrolytes must be high, toxicity and corrosiveness should below. The electrolyte pumping pressure is nearly 14 kg/cm2and at speed should not be less than 30m/s.

TABLE 1
Electrolyte and its concentration

SL NO	Alloy	Electrolyte
1.	Iron based	Chloride solutions in water (mostly 20% NaCl)
2.	Ni based	HCL or mixture of brine and H_2SO_4
3.	Ti based	10% hydrofluoric acid + 10% HCL +10% HNO_3
4.	Co-Cr-w based	Nacl
5.	WC based	Strong alkaline solution

4.1 Electrolyte Flow Arrangement in Electro Chemical Machining

- Proper electrolyte circulation is essential for accurate machining in ECM process.
- The tool must be properly designed to permit a uniform electrolyte flow in all machining areas.
- Insufficient or excessive flows produce undesirable effects during machining.

Divergent flow

- Electrolyte flows from the inside of the tool.
- Then Around the cutting edges and up through the machined hole.
- This method is simple, inexpensive.

Convergent flow

- The electrolyte is admitted through a chamber pressurize the area outside the work and tool.
- Through the valve fluid flow can be controlled.

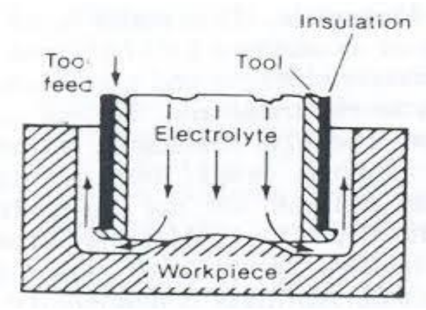

Figure 6: Electrolyte flow

V. PROCESS PARAMETERS OF ELECTRO CHEMICAL MACHINING

Current density - Current density is simply the current that can be passed into a square inch of work area. At low current densities, metal removal rate is small. The relationship between current density and metal removal rate as shown. The electrochemical machine used for a particular application must have sufficient current available to maintain a current density of 50-1500 *A/in2.*

Tool feed rate - Tool feed rate is directly proportional to current density. If the feed rate is increased the electrical resistance of the tool-work gap reduces to allow current to flow resulting in high metal removal rates. Also, it produces good surface finish and accuracy is improved.

Gap between workpiece and tool - The tool and the workpiece are positioned as close together to encourage efficient electrical transmission. Small gap results in high current densities and hence, more metal removal. It is important to maintain a uniform gap between the tool and the workpiece. Any physical contact between the tool and the workpiece results in arcing and serious damage to both the members. The gap size may vary from 0.25-0.76 *mm*. A gap size of 0.25 *mm* is often used.

Velocity of electrolyte flow - Electrolyte flow may be between 15-60 *m/sec*. If the electrolyte flow is too low, the heat and by-products of electrolytic reaction (hydrogen gas bubbles, sludge etc) build in gap of tool and workpiece causing non-uniform metal removal. Too high velocity will cause cavitations, also promoting non-uniform metal removal.

Type of electrolyte, its concentration and temperature - The type of electrolyte selected depends on the tool and the workpiece material. For instance, sodium chloride is cheap and provides good conductivity. However, it is corrosive and hence, cannot be used on tungsten carbide or molybdenum materials. Sodium nitrate is also popular due to its less corrosive nature. But it does not produce a good surface finish as that of sodium chloride. Also, it is more expensive than

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sodium chloride. It is preferred for machining aluminum and copper. The electrolyte in water at various concentrations affect the surface finish produced. Low concentrations decrease the equilibrium machining gap resulting in better surface finish and tolerance control. Electrolyte temperature seriously affects the overcut. The power loss in electrolyte reaction gives rise to an increase in the temperature of the electrolyte. The heat must be carried away from the cutting area so as to maintain stable and steady conditions. Low temperature of electrolyte is conductive to better surfaces finish and tolerance.

5.1 Advantages of Electro Chemical Machining

- The rate of machining does not depend on the hardness of the work piece material
- No physical contact between tool and workpiece. Hence no tool wears
- As the tool does not wear. Soft materials (e.g., copper) may be used for tool fabrication
- No stresses are produced on the work piece surface and have high surface finish
- No burrs form in the machining operation
- High surface quality may be achieved
- Accurate shape with good surface finish can be obtained
- Suitable for mass production applications
- Several tools could be connected to a cassette to make many cavities simultaneously
- ECM process can be easily automated
- Capable of machining metals and alloys irrespective of their strength and hardness.
- Metal removal is due to anodic (workpiece) dissolution. Hence, no thermal effects on the workpiece.

5.2 Limitations of Electro Chemical Machining

- Suitable only for conductive materials.
- Inability to machine sharp interior edges and corners because of very high current densities at these points.
- Space and floor requirements are higher than conventional machines.
- High electrical power is consumed during the process.
- Higher cost and frequent maintenance of equipment.
- Post machining and cleaning is a must to reduce the corrosion of workpiece.
- Electrolyte may cause corrosion of the equipment.
- Only electrically conductive materials may be machined.
- Not environmentally friendly process. The sludge produced in large amounts need to be disposed off.

VI. ECONOMICS OF ELECTRO CHEMICAL MACHINING PROCESS

Electrochemical machining (E.C.M.) is one of the most complicated processes, because of the numerous interconnected machining parameters. This work is directed towards the determination of the optimum operating parameters; this process is based on certain economic machining criteria.

The high initial cost of ECM equipment coupled with tooling set-ups and the requirement of high current capacities, and frequent maintenance of equipment parts makes the process to be economical for mass production and where conventional machining process is not feasible. The negligible tool wear and low cost is somewhat satisfactory from economical perspective. The economic success of ECM depends largely on the choice of applications.

VII. ELECTROCHEMICAL GRINDING (ECG)

Electrochemical Grinding is a variety of ECM that consolidates electrolytic movement with the physical evacuation of material by use of charged grinding wheels. It can deliver burr and stretch free parts without any metallurgical harm brought on by grinding, wiping out the need for secondary machining operations. Similar to ECM, ECG creates no heat to contort fragile segments. It can handle any electrochemically reactive material. The most well-known reason clients pick ECG is for the burr free nature of cut.

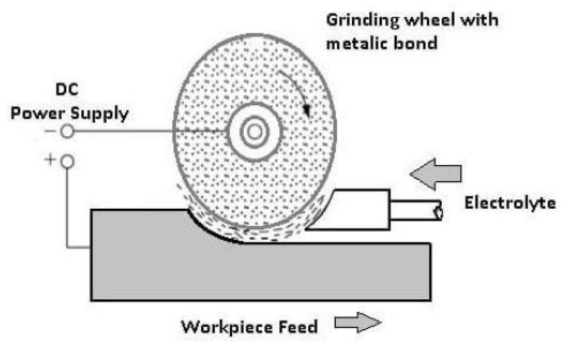

Figure 7: Electro chemical grinding

VIII. PRINCIPLE OF ELECTROCHEMICAL GRINDING

Electrochemical grinding, is also called electrolytic grinding is a variation process of the basic electrochemical machining, wherein material removal of the electrically conductive work material takes place through the combined effect of electrochemical process and the mechanical action of abrasive particles (grinding) on the work material.

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The process makes use of a metallic grinding wheel which is a circular metal plate and is embedded with insulating abrasive particle such as aluminum oxide or diamond, set in a conducting binding material. In this technique, the workpiece plays the role of the anode while the grinding wheel works as a cathode.

8.1 Electro Chemical Grinding Process

The electrolytic fluid is pumped through the gap between the workpiece and the grinding wheel, when a DC voltage is applies current densities are created due to which material from work surface is removed by electrochemical action coupled with abrasive action of grinding wheel.

8.2 Advantages

- Ability to grind any electrically conductive material regardless of hardness.
- MRR are 5 to 10 times greater than Broaching, milling or conventional machining.
- Frequent grinding dressing is unnecessary.

8.3 Disadvantages

- Workpiece must be electrically conductive.
- High equipment cost.
- Not suitable for graining low hardness metals.

8.4 Applications of Electro Chemical Grinding

- Any material which is conductive may be ground by the electrolytic process. But it's most useful application is concerned with hardened steel, cemented carbides, and similar materials.
- This is mainly applied to re-sharpening and reconditioning of carbide tools and other materials that are difficult to grind.
- The grinding pressure is low. It is possible to grind and cut thin sections and thin-wall tubing of difficult materials without distortion or burr.

IX. ELECTRO CHEMICAL HONING

Electrochemical honing is a modification of conventional honing. ECH is a process in which the metal removal capabilities of ECM are combined with the accuracy capabilities of honing. The process consists of a rotating and reciprocating tool inside a cylindrical component. Material is removed through anodic dissolution and mechanical abrasion – 8% or more, of the material removal occurs through electrolytic action. As with conventional ECM, the workpiece is the anode and a stainless-steel tool is the cathode.

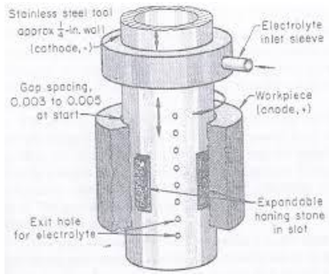

Figure 8: Electro chemical honing tool

Tool consists of a hollow stainless-steel body that has expandable, nonconductive honing stones protruding from at least three locations around the circumference. The tool is rotated and reciprocated on a rigid spindle for precise metal removal from internal cylindrical hole of the workpiece. The honing stones are identical with those used in conventional honing operations, except that they must resist the corrosiveness of the electrolyte. The honing stones are mounted on the tool body with a spring-loaded mechanism so that each of the stones exerts equal pressure against the workpiece. The length of the stones is selected to be approximately one-half the length of the bore being processed.

X. ELECTRO CHEMICAL HONING PROCESS

At the beginning of the ECH cycle, the stones protrude only 0.075-0.127mm from the stainless-steel body, establishing the gap through which the electrolyte flows. The electrolyte enters the tool body via a sliding inlet sleeve from which it exits into the tool-workpiece gap through small holes in the tool body. After passing through the gap, the electrolyte flows from the workpiece through the gap at the top and bottom of the bore. The mechanical action of the tool is the same as with conventional honing; the tool is rotated and reciprocated so that the stones abrade the entire length of the bore. Electrolytes used in ECH are essentially the same as those used in ECM, although the control of pH, composition and sludge is less critical because the abrasive action of the stones tends to correct any resulting surface irregularities. As in ECM, the electrolytes are re-circulated and reused after passing through appropriate filtration, and the most commonly used electrolytes are sodium chloride and sodium nitrate.

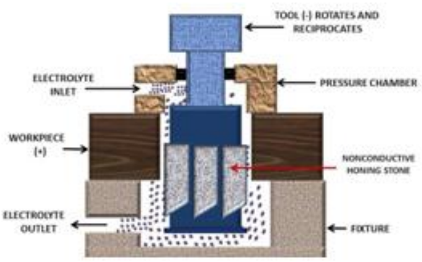

Figure 9: Electro chemical honing setup

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10.1 Advantages

- The most important advantage of this process is that we get both the surface finishing and shaping as a result of this process. That means no need to spend your time on the surface finishing and shaping separately.
- In case hard materials, the tradition machining techniques are not applicable. But this is the perfect process for the hard or tough materials.
- No heat is produced during this whole technique.
- It gives you one of the best surface finishing.
- This method gives you the desired low tolerance.

10.2 Disadvantages

- More number of equipments are required during this process.
- The cost of machines is too much high to carry out this process.
- Skilled labour is needed to implement this metal removing process.
- It is only applicable to the hard materials mostly.

10.3 Applications

- Primarily used in the grinding of Tungsten carbide tool bits.
- Grinding of cutting tools, chilled iron castings, magnet alloys, contour milling of honey- comb structures.
- Used for machining of cemented carbides, satellites, refractory materials, stainless steel and high alloys steels without any burr.
- Chromium plated materials, flame hardened materials and temperature sensitive alloys can be machined without forming thermal cracks and distortion.
- Grinding of super alloy turbine blades.
- Burr free sharpening of hypodermic needles.

XI. CONCLUSION

Electro Chemical Machining has a significant place among the methods of machining of conducting materials. It is applied in cases where alternative methods encounter problems: for operations which are time and hand-labour consuming. Electro Chemical Machining is feasible for the machining of difficult-to-cut materials, complex-shaped parts, and the machining in the difficult-to-reach areas. In some cases, Electro Chemical Machining enables one to perform unique operations, for example, drilling of very small, deep, curved holes. The Electro Chemical Machining processes are in progress, spread into new areas of modern technologies, for instance, micromachining. Electro Chemical Machining today is widely used in processing of materials used in extreme conditions of temperature, loading, friction, wear, corrosion, in Energy, Transportation and Machinery manufacturing industries.

REFERENCES

[1] Von Gutfeld RJ, Sheppard KG (1998) Electrochemical microfabrication by laser-enhanced photothermal processes. *IBM J Res Develop* 42(5):639–653. https://doi.org/10.1147/rd.425.0639

[2] Von Gutfeld RJ, Tynan EE, Melcher RL, Blum SE (1979) Laser enhanced electroplating and maskless pattern generation. *Appl Phys Lett* 35:651–653. https://doi.org/10.1063/1.91242

[3] Electrochemical machining, J. A. McGeough, in "Kirk-Othmer Encyclopedia of Chemical Technology" (5th edition), Vol. 9, pp 590-606, J. I. Kroschwitz (editor), *Wiley-Interscience*, NY 2005.

[4] Machining methods: electrochemical, J. A. McGeough and X. K. Chen, in "Kirk-Othmer Encyclopedia of Chemical Technology" (4th edition), Vol. 15, pp 608-622, J. I. Kroschwitz and M. Howe-Grant (editors), *Wiley-Interscience*, NY 1995.

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