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ANALYSIS AND DESIGN OF THE TRAVELLING WIRE ELECTROCHEMICAL DISCHARGE MACHINING SYSTEM FOR MACHINING NON-CONDUCTING ENGINEERING MATERIALS

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ABSTRACT

The Travelling Wire Electrochemical Discharge Machining (TW-ECDM) process can be applied for cutting of non-conductive engineering materials with the scope of generating intricate shapes and profiles. It is a complex combination of ECM and WireEDM process. In order to meet with the requirements of present day part manufacturing with any kind of non-conducting work materials for achieving enhanced productivity, dimensional quality features and cost reduction criteria the travelling wire electrochemical discharge machining technique has great potential. It is expected to have tremendous application for generating intricate shapes and profiles of advanced non-conducting ceramic materials like zirconia(ZrO_2), silicon nitride (Si_3N_4), alumina (Al_2O_3),diamond, glass, ruby and composites like FRP etc. For better understanding of the TW-ECDM process this research paper includes indepth study of the the basic material removal mechanism of the TW-ECDM process and the design details for the development of travelling wire electrochemical discharge machining setup which will be compatible to the needs of performing the machining characteristics studies and analysis for effective machining of non-conducting engineering materials.

Keywords: Travelling Wire Electrochemical Discharge Machining (TW-ECDM),Non-conducting engineering materials.

1. INTRODUCTION

The researchers are urgently searching for new machining technique to keep up with the development new materials such as engineering ceramics and composites etc. Hence there is a continuous demand for new machining techniques to process such newer materials. The demand for machining hard and brittle materials is steadily increasing in many applications. Presently various non-traditional machining processes are available. These processes are EBM, LBM, WJC, USM etc. The inherent problem associated with these processes are thermal damage due to large heat affected zone (HAZ), high tool wear rate , low material removal rate, high surface roughness, poor dimensional accuracy etc. The electrochemical machining (ECM), the electrical discharge machining (EDM) and the electrochemical arc machining (ECAM) are found to have scope for machining such hard and tough materials, but the application of such processes are really limited to conducting materials only. However ,the requirements of such material machining have led to the development of another module of high energy density machining process called electrochemical discharge machining (ECDM). ECDM has greater applicability of machining non-conducting engineering materials. Now-a-days the requirement is of producing parts of intricate shapes and profiles as well as achieving enhanced productivity, dimensional quality features at reduced cost. While producing parts of conducting materials , the Wire Electrical Discharge Machining gives a possible solution. WireEDM is a thermo-electrical process in which the material is eroded from the work piece and the wire electrode (tool) is separated by a thin film of dielectric fluid. The dielectric is supplied to the machining zone to flush away the eroded particles. The wire is continually fed from a spool by a stepper motor where as the work piece is given movement by a numerically controlled servo feed mechanism and thus intricate shapes are produced. But this method is not at all useful for non-conducting engineering materials.

To cater with the needs for both ECDM and Wire-EDM process a new method is proposed. This method is termed as Travelling Wire Electrochemical Discharge Machining. This method is useful for cutting of non-conductive engineering materials with the scope of generating intricate shapes and profiles. The TW-ECDM process is expected to have tremendous application for generating intricate shapes and profiles on advanced non-conducting ceramic materials like zirconia(ZrO_2), silicon nitrate(Si_3N_4), alumina (Al_2O_3), diamond ,glass, ruby and composites like FRP etc. Keeping this above considerations in view, the object of the present research paper includes the analysis of the basic material removal mechanism in TW-ECDM process and design and development of TW-ECDM system for effective machining of non-conducting engineering materials.

2.FUNDAMENTALS OF MATERIAL REMOVAL MECHANISM IN TW-ECDM

The Travelling Wire Electrochemical Discharge Machining is the complex combination of electrochemical machining (ECM) and wire electrical discharge machining (WEDM). In electrochemical machining tool is used as negative electrode or cathode whereas the work piece is used as positive electrode or anode and the flow of electrolyte occurs between the work piece and the tool. In Wire EDM the conductive wire is continuously moving and the work- piece is anode. Between the spark gap a dielectric fluid is continuously pumped. In electrochemical discharge machining the tool is cathode and an auxiliary electrode is used as anode instead of work piece. In TW-ECDM process the pulsed D.C power is supplied between the wire and the auxiliary electrode and the sparking takes place between the wire and the electrolyte and hydrogen and vapor bubbles are accumulated and insulating layer is formed near the wire surface. With the further increase of applied voltage , sparking from wire takes place. As the job surface is kept in the sparking zone, the material from the job surface is removed mainly due to melting and vaporization of work piece material.

The electrochemical reactions in TW-ECDM are given as follows:

Cathode (Wire) reactions:

$M^+ + e \longrightarrow M$ (Wire)

$2H^+ + 2e \longrightarrow H_2 \uparrow$ (In acidic solution)

$2H_2O + 2e \longrightarrow 2\,(OH)^- + H_2 \uparrow$ (In alkaline solution)

Anode (auxiliary electrode) reaction:

$M \longrightarrow M^+ + e$ (Wor kpiece dissolution)

$2H_2O \longrightarrow O_2 \uparrow + 4H^+ + 4e$ (In acidic electrolyte solution)

$4\,(OH)^- \longrightarrow 2H_2O + O_2 + 4e$ (In alkaline electrolyte solution)

$2Cl^- \longrightarrow Cl_2 + 2e$ (In neutral solution such as NaCl)

The important electrochemical phenomena are as follows:

a) Hydrogen evolution at cathode;
b) Oxygen evolution at anode;
c) Metallic dissolution at anode;

The inter electrode gap is very large in TW-ECDM compared to the ECM process. Hence the chances of metal removal from the auxiliary electrode due to electrochemical dissolution is very small because of the fact that very low current passes through the inter electrode gap . A pulsed D.C power supply of high voltage is applied between the tool (wire) (or cathode) and the auxiliary electrode (or anode). The rate of generation of hydrogen gas bubbles is very high in the vicinity of the tool . As a result of heating the electrolyte ,some electrolyte is evaporated and steam is formed. The gas bubbles are usually low ionic positively charged bubbles. Under the normal condition of bubble formation, with the increment of voltage supply , a critical or threshold voltage is attained, where sparking will be observed to take place in the gap. The critical voltage at which sparking starts, will depend upon the concentration, conductivity of electrolyte and the tool geometry. As the voltage is further raised, then quite violent spark will occur. The work piece material may be removed from the localized sparking zone due to melting and vapourisation.

Each electrical discharge causes a focussed stream of electrons. These streams move with a very high velocity and acceleration from the cathode (or tool) towards the auxiliary electrode. These streams ultimately creates compression shock waves on the work piece surfaces. This phenomenon is accomplished within a few microseconds. The temperature of the spot hit by the electrons may rise to a very high magnitude. As this temperature is higher than the melting point of the work piece material, it melts and finally evaporates. The high pressure of the compressive shock wave creates a blast causing matallic vapors to form wear products in the shape of metallic globules., leaving craters in the work piece surface. As the low pressure compressive shock waves are developed on the tool and the positive ions strike the tool surface with less momentum ,lesser tool wear takes place. Thus the material removal process in Travelling Wire Electrochemical Discharge Machining is very complex in nature which is governed by various process parameters .

In order to achieve the effective and controlled material machining, the following process parameters are primarily to be properly and optimally controlled.

a) Applied voltage;
b) Frequency of the applied voltage;
c) Electrical power supply pulse form features;
d) Wire tension;
e) Wire feed rate;
f) Temperature, concentration and type of electrolyte;
g) Inter electrode gap;

The machining criteria during travelling wire-ECDM operation can be considered as :

(a) Material removal rate ;
(b) Overcut;
(c) Heat affected zone; and
(d) Surface roughness etc.

The experimental set up of TW-ECDM has to be developed so that the process parameters are to be properly controlled to achieve the good machining performance and criterial yield.

3. DEVELOPMENT OF THE EXPERIMENTAL SETUP

Keeping in view the influences of various process parameters of Travelling Wire Electrochemical Discharge Machining, the experimental setup is to be indigenously developed for performing experimental studies. The total TW-ECDM system consists of various subsystems as follows:

(a) Wire feeding unit;
(b) Work-table feeding unit;
(c) Machining chamber;
(d) Electrolyte supply unit;
(e) Electrical power supply unit;

Fig.1 exhibits the schematic diagram of the Travelling Wire Electrochemical Discharge Machining System.

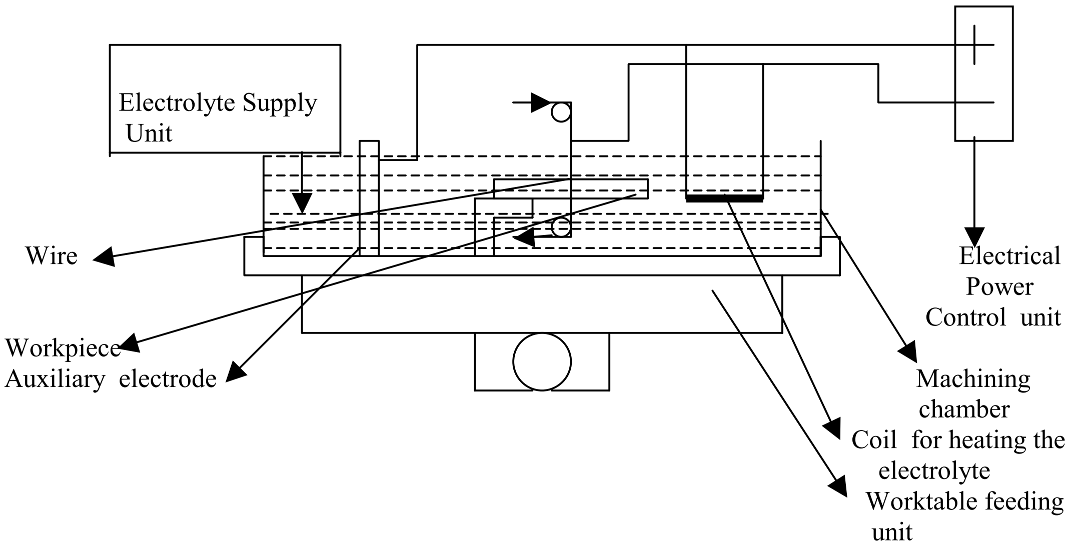
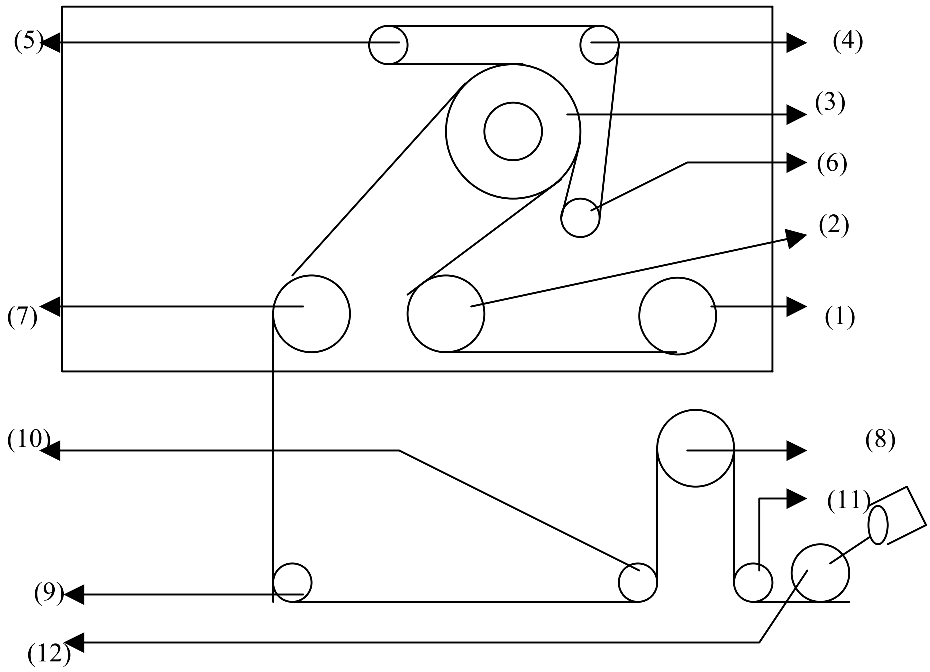


FIG. 1 SCHEMATIC DIAGRAM OF TRAVELLING WIRE ELECTROCHEMICAL DISCHARGE MACHINING SYSTEM

3.1 THE WIRE-FEEDING UNIT

The wire feeding unit is made up of several rollers, pulleys and wire spool is fitted with its vertical wall. The arrangement of the wire feeding unit is shown in Fig 2.



Legend:
(1)- De-coiling spool , (2)- First intermediate roller , (3) -Tension roller , (4,5 & 6)- Idler guide rollers, (7) -Second intermediate roller, (8,9,10 & 11) -Intermediate pulleys, (12) -Recoiling spool

FIG. 2 SCHEMATIC DIAGRAM OF THE WIRE-FEEDING UNIT IN TW-ECDM SYSTEM

The wire is driven out from the de-coiling spool and passing through the first intermediate roller it is wound around a tension roller ,the wire around which is guided by three idler guide rollers. The velocity range of wire is from 1m/min to 15 m/min. A provision for wire tension is added with the tension roller by introducing a system of simple band brake. The wire is pressed against the band up to a certain length of circumference. When the weights are hanged in the band brake system it actually applies a tension on the wire. The wire tension can be varied by varying the weight. After touching the second intermediate (free) roller the wire ultimately is wound around four intermediate pulleys at different positions successively and ultimately the wire is collected in a recoiling spool. The wire feed rate can be controlled by controlling the speed of the stepper motor attached with the recoiling spool.

3.2 THE WORK TABLE FEEDING UNIT

The worktable feeding unit is basically a machine vice which is made of stainless steel block .The block is insulated from the machining chamber by means of rubber sheet of a certain thickness.. Through the block longitudinally one through hole is made. Through this hole one mild steel pitch screw is inserted , which is supported at both the ends by a pair of external return type re-circulating ball screws. The re-circulating ball screw help the pitch screw to traverse back and forth in one of the two perpendicular directions. The re-circulating ball screw is made external return type because of ease of maintenance and replacement. The pitch screw can be operated by means of a stepper motor attached with it and if the stepper motor is detached ,the pitch screw can also be operated by means of a hand wheel. The vice may be kept on steel balls in the machine bed as rolling friction is smaller than the sliding friction.

3.3 THE MACHINING CHAMBER DETAILS

The machining chamber is comprised of stainless steel sheet. In the center of machining chamber, there is a provision for keeping the work piece. Four steel channel pieces are welded at a suitable distance to prepare the seat for the work piece. A vertical scale is attached with one of the channel piece to measure the height of the electrolyte. The machining chamber has length 300 mm ,breadth 300 mm and height 200 mm. The thickness of steel sheet is 3-5 mm. The auxiliary electrode is a vertical plate and a horizontal scale is attached at the center of the top edge of the vertical plate. The horizontal scale is provided in order to measure the horizontal displacement of the auxiliary electrode which in turn helps to measure and control the inter electrode gap. In the base and side wall of the machining chamber ,pulleys are attached, which helps in movement of wire through out the machining chamber. The electrolyte reservoir is attached with the side wall of the machining chamber in order to supply electrolyte. Stainless steel is chosen as the material for machining chamber because it is corrosion resistant in the alkaline medium.

3.4 THE ELECTROLYTE SUPPLY UNIT

The electrolyte supply unit is in the form of an electrolyte reservoir. The electrolyte reservoir is in the form of flask. The flask is made of glass and is attached with a vertical stand by means of a clamp. A stop cock is attached with the flask to control the flow of electrolyte. The electrolyte is added to the machining chamber from the reservoir in the form of drops instead of flow from pipe. As the evaporation rate is very slow the make up electrolyte should also be added very slowly. If electrolyte is fed with high velocity, there will be no formation of insulating layer or gas bubbles. Hence for this thermal consideration the electrolyte should be added drop by drop. The electrolyte used here is the solution of NaOH or NaCl or KOH or $NaNO_3$ salt.

3.5 THE ELECTRICAL POWER SUPPLY UNIT

The Travelling Wire Electrochemical Discharge Machining system demands for a voltage of 20 to 50 volts and a high current ranging from 0 amp to 230 amp depending on the rate of material removal and other parametric criteria requirement. Keeping in view of this objective pulsed D.C power supply system is arranged . The pulse form is either square or rectangular. The applied voltage can be changed by means of a variac and the frequency of the applied voltage can be changed by chopping circuit. The electrical pulse form features can be controlled by modulators. Main power line has 440 volts ,3 phase, A.C power which is converted to low voltage pulsed D.C power supply by a step down transformer and silicon controlled rectifier unit. The pulse on time varies from 0.1μs to 1.65 μs and duty factor varies from 5% to 15% . The positive terminal of power supply unit is connected with auxiliary electrode and one end of the coil heating the electrolyte. The negative terminal of the power supply unit is connected with wire and another end of heating coil. Thus temperature of the electrolyte is controlled electrically from 40^oC to 90^oC. The voltage and current can be recorded with a voltmeter and ammeter. Arrangement for having adequate protective circuits for the transformer, rectifier and machine have been provided against short circuit and overload conditions.

4. CONCLUSIONS

The traveling wire electrochemical discharge machining will be a very effective and feasible process for contour cutting operation on non-conducting engineering materials. The thermo-mechanical phenomenon has been identified as the main mechanism responsible for material removal in TW-ECDM . The material removal during machining of non-conducting ceramic work piece in TW-ECDM process, mainly takes place due to spark discharge action across the gas bubble layers formed on the work piece surface. The machining chamber is insulated from the machine vice by means of insulating sheets. The wire feeding unit helps to vary both the wire feed rate and wire tension by mechanical means. By means of proper electric circuitry the electrical pulse form features are varied. The other process parameters are varied by properly designing the machining chamber, work table feeding unit and electrolyte supply unit. It is evident that the method is more effective for wire cutting of non-conducting engineering materials considering the economy of the machining process, dust free machining environment and also the capacity of machining the complex profiles. Hence at this stage, the research findings will be quite useful and step forward for cutting of various advanced ceramics and composite materials using Traveling Wire Electrical Discharge Machining Process.

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