Effect of Process Parameters on Performance Measures of Wire EDM for A2 Tool Steel, Orthopedic Material

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Abstract **-** Wire electrical discharge machining (WEDM) is a specialized thermal machining process capable of accurately machining parts with varying hardness or complex shapes, which have sharp edges that are very difficult to be machined by the main stream machining processes. The focus of this thesis is on machining of titanium with WEDM because of the abovementioned features of WEDM and its suitability for machining titanium and its alloys. On the other hand, unconventional machining processes especially Wire Electrical Discharge Machining (WEDM) are more appropriate techniques for machining difficult –to-machine materials like titanium and its alloys. The outstanding characteristics of titanium alloys such as their compatibility and noticeable physical, mechanical and biological performances has led to increased application of them in various industries especially in biomedical industries over the last 50 years.
It reports on the WEDM research involving the optimization of the process parameters surveying the influence of the various factors affecting the machining performance and productivity. A wide range of WEDM industrial applications are reported together with the development of the hybrid machining processes. The final part of the paper discusses these developments and outlines the possible trends for future WEDM research. The paper also highlights the adaptive monitoring and control of the process investigating the feasibility of the different control strategies of obtaining the optimal machining conditions.

Keywords **-** Wire Electrical Discharge Machining (WEDM), Process optimization; Cutting rate; Material removal rate; Surface finish Electric discharge machining (EDM),

I. INTRODUCTION

In mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing. Nevertheless, such materials are difficult to be machined by traditional machining methods. Hence, non-traditional machining methods including electrochemical machining, ultrasonic machining, electrical discharging machine (EDM) etc. are applied to machine such difficult to machine materials show in fig.1. WEDM is popular in all conventional EDM process, which used a wire electrode to initialize the sparking process. WEDM process with a thin wire as an electrode transforms electrical energy to thermal energy for cutting materials. With this process, alloy steel, conductive ceramics and aerospace materials can be machined irrespective to their hardness and toughness. Furthermore, WEDM is capable of producing a fine, precise, corrosion and wear resistant surface. A continuously travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05-0.30 mm, which is capable of achieving very small corner radii. There is no direct contact between the work piece and the wire, eliminating the mechanical stresses during machining. The WEDM is a well-established machining option for manufacturing geometrically complex or hard material parts that are extremely difficult-to-machine by conventional machining processes. The non-contact machining techniques have been continuously evolving in a mere tool and die making process to a micro-scale application.

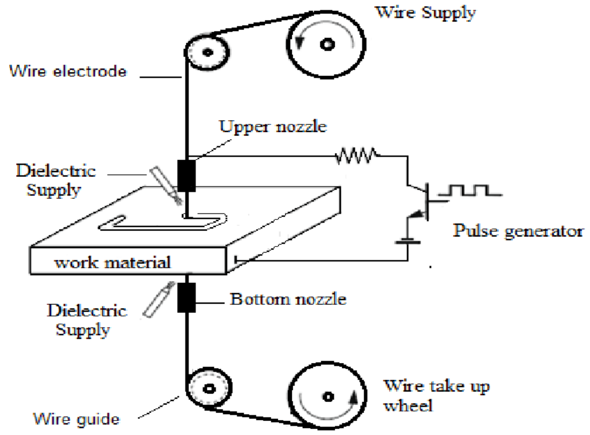

Figure 1: Wire-EDM setup

A wire-EDM process is one of the types of EDM process (the other being Die-Sinking EDM). In wire EDM, the conductive materials are machined with a series of electrical discharges (sparks) that are produced between an accurately positioned moving wire (the electrode) and the work piece.
High frequency pulses of alternating or direct current is discharged from the wire to the work piece with a very small spark gap through an insulated dielectric fluid (water). Many sparks can be observed at one time. This is because actual discharges can occur more than one hundred thousand times per second, with discharge sparks lasting in the range of 1/1,000,000 of a second or less. The volume of metal removed during this short period of spark discharge depends on the desired cutting speed and the surface finish required. The heat of each electrical spark, estimated at around 15,000° to 21,000° Fahrenheit, erodes away a tiny bit of material that is vaporized and melted from the work piece. (Some of the wire material is also eroded away) These particles (chips) are flushed away from the cut with a

stream of de-ionized water through the top and bottom flushing nozzles. The water also prevents heat build-up in the work piece. Without this cooling, thermal expansion of the part would affect size and positional accuracy. The wire is usually made of brass, copper, or tungsten; zinc- or brass-coated and multi coated wires are used. The wire diameter is typically about 0.30 mm (0.012 in.) for roughing cuts and 0.20 mm (0.008 in.) for finishing cuts. The wire travels with a constant velocity in the range of 0.15 to 9 m/min, and a constant gap (kerf) is maintained during the cut. In 1969, the swiss firm Agie produced world's first wire-EDM machine. Typically in the early 70's these machines were typically slow, cutting about 2 sq. inches an hour. There speeds went up to 6 sq. inches per hour in early 80's. Today the machines are equipped with automatic wire threading and can cut around 20 times faster than initial machines. The earliest numerically controlled machines were conversions of punched-tape vertical milling machines. The first commercially available NC machine built as a wire-cut EDM machine was manufactured in USSR in 1967. Machines that could optically follow lines of master drawing were developed by David H. Dulebohn's grouping 1960s (1). It was only towards the mid of the 1970s, when computer numerical control (CNC) drawing plotter and optical line follower techniques were produced. Dulebohn later used the same plotter CNC program to directly control the EDM machine and hence the first CNC EDM machine was produced in1976 that brought about a major evolution of the machining process. As a result, the broad capabilities of the WEDM process were extensively exploited for any through-hole machining owing to the wire, which has to pass through the part to be machined. The review presented in this paper is based upon the major and current research trends carried out by the different researchers of the world who utilized different fields related to the Wire-EDM technology and many ideas were obtained regarding the improvements of the process.

II. MAIN AREAS OF RESEARCH

A. Modeling and Simulation Modeling and simulation always help to better interpret and predict the results which are otherwise difficult to understand. Here, we use models, prototypes and stimulators, either statically or overtime to develop data as a basis for making managerial or technical decisions without even testing it in Real life.

E. Weingartner, F. Kuster and K. Wegener (2) studied the influence of type of heat source on modeling single discharges as well as influence of temperature dependent material properties and latent heat of fusion and vaporization on simulation results by considering a heat source modeled on three different shapes ; Heat source, disc heat source and time dependent heat source. However the time dependent heat source was found to be more suitable to predict the shape of eroded craters (Depth was decreased when latent heat was considered). Hence latent heat of fusion and vaporization showed to have significant influence on simulation results.

Amit Kumar Gupta and Dr. Sanjeev Kumar (3) Conducted experiments on high carbon chromium Steel with a wire of diameter 0.2 mm and obtained data was analyzed using response surface methodology. The results of ANOVA indicated that proposed a mathematical model can adequately describe the performance within limit off actors being studied and founded that high pulse on time, low pulse of time and low gives optimal value of cutting rate.

Ravindranath Bobbili, V. Madhu and P. K. Gogia (4) attempted to establish the relation between parameters by employing Buckingham Pi theorem to model the input variables and Thermo physical characteristics of Wire EDM and founded that the results predicted by the model regarding material removal rate and surface roughness work well matching with experiment results.

S. Ben Salem, W. Tebni, E. Bayraktar (5) developed the surface roughness model for parameters of current intensity electrode type and workers material for an EDM process using experimental design method. However the mathematical model was itself obtained by experimental design method and relatively small number of designed experiments was required to generate useful information and developing the predictive equations for surface roughness.

Mu-Tian Yan, Chi Cheng Fang (6) proposed a genetic algorithm-based fuzzy logic controller to investigate the dynamic performance of the closed-loop wire tension control system. Experimental results demonstrate that the developed wire transport system can result in satisfactory transient response, steady-state response and robustness. The proposed genetic algorithm-based fuzzy logic controller can obtain faster transient response and smaller steady-state error than a PI controller.

B. Optimization - Here optimization signifies the formulation of the best possible output within a given set of elements or conditions. However it involves various methods such as Taguchi's method which can be applied to find optimum process parameters, ANOVA (analysis of variance) to study performance characteristics, Regression analysis for estimating predicted values of the parameters.

Y.S. Liao, J.T. Huang and H.C. (7) Proposed an effective and precise way of determining the appropriate machining parameters based on Taguchi design method and ANOVA which was time effective and cost saving as well. The objective was to achieve shortest machining time whilst at the same time, satisfying the requirements of accuracy and surface roughness. They found that the table feed and Pulse on time have a significant influence on material removal rate, gap voltage and total discharge frequency however, gap width and surface roughness are mainly influenced by pulse on time. Hence larger table feed and a smaller Ton will result in higher value of surface roughness.

Pujari Srinivasa Rao, Koonu Ramji and Beelasatyanarayana (8) besides presenting optimal combination of parameters for surface roughness and material removal rate for Aluminum 2014 T6 alloy also developed mathematical models which predicted the SR and MRR with high Regression coefficient value with the help of Optimization of performance measures by hybrid genetic algorithm its results clearly showed that a sacrifice in cutting efficiency is essential for production of Quality Surfaces and vice versa. White layer thickness measurements were made for suggested the combination of parameters whose magnitude or value is relatively high when compared to heavy and other light metals.

Shivkant Tilekar, Sankha Shurva Das, P.K. Patowari (9) included effect on kerf width along with surface roughness of Aluminum and mild steel using single objective Taguchi method. both the parameters were measured by surface profile meter and optical microscope respectively. Both kerf width and surface roughness were minimized successfully and process parameters word stated ANOVA showed that in case of kerf width wire feed rate and Spark on times have significant effect on Aluminum and mild steel respectively.

C. Ultrasonic Vibrations The introduction of ultrasonic vibrations is one of the methods to improve the machining performance of difficult to machine materials. It can cause an easy debris removal as well as enhancement of molten metal ejection due to creation of large pressure change between electrode and work piece .Hence ultrasonic vibrations can be mainly applied for finishing process.

Chaiya Praneetpongrung, Yasush Fakuzawa, Shigeru Nagasawa and Ken Yamashita (10) studied the effects on combined ultrasonic vibrations on machining properties of Si3N4. They found that ultrasonic vibrations should be applied after transition time is passed however large amplitude values do not always contribute to large MRR. However surface roughness was increased after introduction of ultrasonic vibration.

D. Dry Machining Dry Wire EDM is a modification of oil wire EDM process in which the liquid dielectric is replaced by high velocity gaseous dielectric like Helium, Argon, oxygen, air extra. Flow of high velocity air into the gap facilitates removal of debris and prevents the excessive heating of tool and work piece.

C.C. Kao, Jio Tao, Sangwon Lee and Alber J (13) investigated the dry wire EDM on thin work Pieces by conducting the experiment in air. The results after experiments showed that not all thin work materials could be machined using dry wire EDM .the increase and work piece thickness and work material melting temperature had an adverse effect on MRR.

E. Effects The changes in process parameters always have significant effect on the performance characteristics of wire EDM. Some of the studies carried out regarding these effects have been mentioned here.

J. Prohaszka, A.G. Mamalis, N. M. Vaxevaxevanidis (21) conducted experiments regarding choice of suitable wire electrode materials and influence of properties of these materials on machinability of wire EDM. they found that materials used for fabrication of wire electrodes must be characterized by small work function and high melting and evaporation temperatures. However by coating already used copper, brass, steel and molybdenum wires by a layer of materials processing a small work function such as magnesium, alkaline metals and alkaline earth metals may increase the cutting efficiency during wire EDM.

J. A. Sanchez, J. L. Rodil, A. Herrero, L.N. Lopez De Lacalle and A. Lamikiz (22) studied the corner geometry by successive cuts (roughing and finishing) and effect of cutting speed limitation on the accuracy of wire EDM corner cutting. They found corner radius as an important function in the output results obtained. However in finishing cuts, the value of limitation depends on factors such as work piece thickness, corner radius and number of finishing cuts. it is possible to achieve and optimum fit along the whole corner (bath at 45o and at exit) since the materials are removed by previous cuts were not constant.

H. Singh and R. Garg (23) studied effects of various process parameters on wire EDM on MRR of hot die Steel (H-11) using one variable at a time approach. it was concluded that wires feed and wire tension had no effect on MRR however pulse on time parameter which is increased can also increase the MRR. However MRR will decrease with an increasing pulse of time and peak current also and increase in Servo voltage decreases MRR.

E. Weingartner, K. Wegener and F. Custer (24) after studying the effect of work piece circumferential speed in wire EDM (wire electrical discharge dressing) found that the size of craters formed and MRR are both increases with increase in relative speed. based on simulation results using thermo-electrical model, it was found that higher melting efficiencies can be achieved with high relative speed.

F. Improvements and Developments (25) there is always a scope of improvement in any type of machining process by developing a method or a proper combination of process parameters. wire EDM also improved from its beginning in 1970's till today. some of the recent improvements and development are:-

Oana Dodun, Laurentiu Slatineanu, Lorele, Gherman (26) proposed to devices which should be able to act on the tool electrode in order to improve the machining process efficiency. One of the solution proposes the use of electromagnetic subsystems, while the second solution is based on the use of a sub assembly electric motor-gear box could be applied for periodically changing the wire tool electrode speed.

G. Composite Materials Composite material is made from 2 or more constituent materials with significantly different physical or chemical properties that when combined, produce a material with characteristics different from individual components. Here the process parameter as well as machining capability of composite materials such as ceramic semiconductors carbon materials has been studied with reference to wire EDM and EDM.

B. Lavwers, J.P. Kruth, W. Liu, W. Earaerts, B.Schacht and P. Bleys (34) presented a detailed investigation of the material removal mechanism of some commercially available electrical conductive ceramic materials through analysis of debris and surface/subsurface quality. ZrO2-based, Si3N4-based and Al2O3-based ceramic materials with additions of electrical conductive phases like TiN & TiCN were studied. it was found that besides the typical EDM material removal mechanism like melting/ evaporation spalling, other mechanism such as oxidation and decomposition of base material can occur. the latter especially occurs inside EDM of Si3N4-Tin using deionized water. Further, spelling effect was proud to be strongly related of formation cracks which was not recognized in machining of ZrO2-Tin which has higher fracture toughness, compared to others.

S. Lopez, C.F. Gutierrez-Gonzalez, G.Mata-Osore, C. Pecharroman, L.A. Diaz, R.Torrecillas and J.S. Moya (35) presented the properties of ceramic based oxide/semiconductor/ metal nano composites and tested. The possibility of turning their composition in order to confer the machinability by EDM. they found that by adding a semiconductor and metal to a high performance ceramic, a composite that combines the good electrical conductivity of both semiconductor and metal, with high Mechanical properties of matrix can be produced the metal place a double role (a) from mechanical point of view the good ceramic/ metal interface confers the composite excellent Mechanical properties. (b) from electrical point of view, Nickel confer the machinability by EDM to samples with sufficient low resistivity.

D. Hanaoka, Y Fukuzawa, C. Ramirez, P.Minrazo, M.J. Osend. M. Belmonte (36) studied the discharge behavior of Si3N4 ceramic/carbon nanostructure composite and EDM was carried out using arresting electrode method which help in obtaining a better hole-edge shape as compared to normal method and insulating Si3N4 ceramics and Si3N4/ CNT and Si3N4/ GNP. Nano composites could be machined by this method. however properties of electrode we're ratio and surface roughness were better in conductive materials but the MRR was found better in insulting materials.

H. Other Key Studies Kapil Gupta, Surjeet K Chaube, NK Jain (32) conducted experiments to find out effect of four important wire EDM parameters namely voltage, pulse on, pulse of time and wire feed rate on wire breakage frequency, surface roughness and machining rate of brass in order to bracket their ranges from available ranges in wire EDM machine for the ease of manufacturing of meso Gears. they concluded that manufacturing of meso-gears using bracket ranges of parameters resulted in burr-free uniform teeth profile, good roughness characteristics and manufacturing quality DIN standard up to 6 which was much better than quality of gears manufacturer manufactured by conventional process the low discharge energy parameter setting and high voltage and high Pulse on time were suggested here.

III. PROCESS

The material removal mechanism of WEDM is very similar to the conventional EDM process involving the erosion effect produced by the electrical discharges (sparks). In WEDM, material is eroded from the work-piece by a series of discrete sparks occurring between the work piece and the wire separated by a stream of dielectric fluid, which is continuously fed to the machining zone [4]. However, today's WEDM process is commonly conducted on work pieces that are totally submerged in a tank filled with dielectric fluid. Such a submerged method of WEDM promotes temperature stabilization and efficient flushing especially in cases where the work piece has varying thickness. The WEDM process makes use of electrical energy generating a channel of plasma between the cathode and anode [5], and turns it into thermal energy [6] at a temperature in the range of 8000–12,000 vC [7] or as high as 20,000 vC [8] initializing a substantial amount of heating and melting of material on the surface of each pole. When the pulsating direct current power supply occurring between 20,000 and 30,000 Hz [9] is turned off, the plasma channel breaks down.

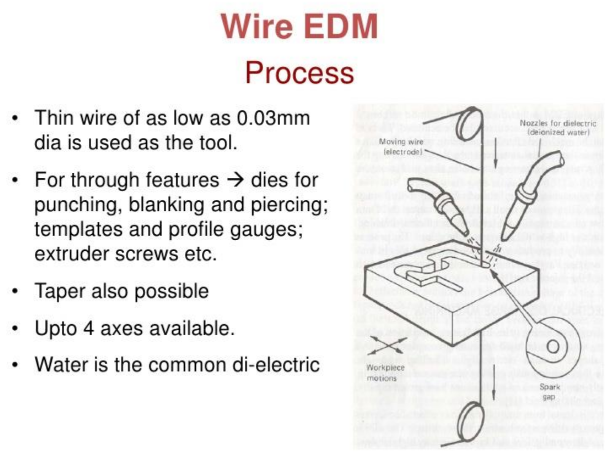

Figure 2: Wire-EDM process

While the material removal mechanisms of EDM and WEDM are similar, their functional characteristics are not identical. WEDM uses a thin wire continuously feeding through the work piece by a microprocessor, which enable parts of complex shapes to be machined with exceptional high accuracy. A varying degree of taper ranging from 15v for a 100 mm thick to 30v for a 400 mm thick work piece can also be obtained on the cut surface show in fig.2. The microprocessor also constantly maintains the gap between the wire and the work piece, which varies from 0.025 to 0.05 mm [2]. WEDM eliminates the need for elaborate pre-shaped electrodes, which are commonly required in EDM to perform the roughing and finishing operations. In the case of WEDM, the wire has to make several machining passes along the profile to be machined to attain the required dimensional accuracy and surface finish (SR) quality. Kunieda and Furudate [10] tested the feasibility of con-ducting dry WEDM to improve the accuracy of the finishing operations, which was conducted in a gas atmosphere without using dielectric fluid. The typical WEDM cutting rates (CRs) are 300 mm2/min for a 50 mm thick D2 tool steel and 750 mm2/min for a 150 mm thick aluminum [11], and SR quality is as fine as 0.04–0.25 lRa. In addition, WEDM uses deionised water instead of hydrocarbon oil as the dielectric fluid and contains it within the sparking zone. The deionised water is not suitable for conventional EDM as it causes rapid electrode wear, but its low viscosity and rapid cooling rate make it ideal for WEDM [12].

IV. FUZZY CONTROL SYSTEM

The proportional controllers have traditionally been used in the servo feed control system to monitor and evaluate the gap condition during the WEDM process. However, the performance of the controllers was limited by the machining conditions, which considerably vary with the parameters settings. Several authors [7.8] proposed the sparking frequency monitoring and adaptive control systems based on the fuzzy logic control and the adjusting strategies, which can be applied to a wide range of machining conditions. As a result, many conventional control algorithms based on explicit mathematical and statistical models have been developed for EDM or WEDM operations [6–7]. Kinoshita et al. [7] investigated the effects of wire feed rate, wire winding speed, wire tension and electrical parameters on the gap conditions during WEDM. Several authors [23, 28] have also developed a pulse discrimination sys-tem providing a means of analyzing and monitoring the pulse trains under the various WEDM conditions quantitatively. In addition, the fuzzy logic controller does not require any comprehensive mathematical models adapting to the dynamic behavior of the WEDM operation [7]. Although these types of control systems can be applied to a wide range of machining conditions, it cannot respond to the gap condition when there is an unexpected disturbance [5].

In recent years, the fuzzy control system has been applied to WEDM process to achieve optimum and highly efficient machining. Several authors claimed that the fuzzy logic control system implements a control strategy, which captures the expert's knowledge or operator's experience in maintaining the desired machining operation [6]. Liao and Woo [15] also designed a fuzzy controller with an online pulse monitoring system isolating the discharging noise and discriminating the ignition delay time of each pulse. EDM pulses can be classified into open, spark, arc, off or short, which are dependent on the ignition delay time, and have a direct influence on the MRR, SR, electrode wear and accuracy of the part [20, 24].

V. CONCLUSIONS

From the above literature review, we can hereby conclude that Latent heat of fusion and vaporization influences the simulation results, high pulse on time, low pulse off time and low servo voltage gives optimal value of cutting rate, surface roughness is influenced by pulse on time and ultrasonic vibrations (which were found to be more significant in roughing conditions and probability of rapture wire was reduced because of its introduction), Wet wire-EDM gives better surface integrity as compared to dry Wire-EDM, open circuit voltage and pulse duration were found to be the most effective parameters on WWR, MRR will decrease with increasing pulse off time and peak current, however increase in servo voltage decreases MRR, high melting efficiencies can be achieved with high relative speeds. However, many other conclusions were made related to the different fields in wire-EDM including modeling, dry machining, composite materials, optimization, ultrasonic vibrations and other investigations, effects, improvements & developments suggested were also mentioned. With the continuous trend towards unattended machining operation and automation, the WEDM process has to be constantly improved to maintain as a competitive and economical machining operation in the modern tool-room manufacturing arena. To sum up, we can say enormous research has been done in the past and large amount of work can still be done in the future on the topic, so that WEDM can serve the purpose of high speed machining with good quality products in short time period and at reduced costs.

VI. FUTURE SCOPE

Need for finding optimal combination of parameters for different tool materials used for work materials.

i) Responses like roundness, circularity, cylindricity, machining cost etc may be considered in further research.
ii) For the estimation of process parameters, the work being carried out can be compared by considering different methods such as multiple relation analyses, ANOVA or F-Test. Similarly comparison can be made between Fuzzy control or Orthogonal techniques.
iii) A lot of research work still needs to be carried out in the field of Wire EDM by machining Super alloys such as Monel K500, Hastelloy composites, Different grades of steel utilizing other process parameters and using deferent Techniques.

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