Optimization of Electric Discharge Machining Process Parameters for AISI 1045 Medium Carbon Steel using Taguchi Design of Experiment.

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AUGUST, 2022

Declaration

I declare that this thesis is titled "Optimization of Electric Discharge Machining process parameters for AISI 1045 Medium Carbon Steel using Taguchi Design of Experiment."

The work presented in it is my own and has been generated by me as a result of my original research.

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Thesis Advisor: _________________

(Dr. Uzair Khaleeq uz Zaman)

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Abstract

The demand for alloy materials with high hardness, toughness, and impact strength has increased with the growth of the manufacturing industry. These materials are extremely difficult to manufacture using standard techniques. Hence, non-conventional machining is used to solve this problem. Wire cut electric discharge machine is one of them. Thus, to attain the required outcome or productivity, it is necessary to control the input parameters that affect the response factors. This research aims to optimize the wire cut electric discharge machining process parameters using the Taguchi experiment (D.O.E.) design for AISI 1045 medium carbon steel. In this work, experiments are performed in an automotive sector to analyze the influence of WEDM process parameters such as current, voltage, and pulse on time on material removal rate (M.R.R.) for AISI 1045 medium carbon steel. The signal-to-noise (S/N) ratio and analysis of variance are used to analyze the impact of error in this experiment, establishing the best process parameters for optimizing the material removal rate. According to the present investigation, it was found that the current has a significant effect on the material removal rate. The optimal process parameter settings for higher material removal rate based on the Taguchi D.O.E. were found to be I=16amp, V=50volt, pulse on-time =100μs. The paper's conclusion includes the disclosure of findings, analysis, and judgment.

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Chapter 1: Introduction

1.1 Background

In the 1770s, an English scientist came up with the idea of wire-cut electric discharge machining. Russian scientists developed techniques for using and managing the machining method's eroding effects.[1], [2]. Joseph Priestly first noticed wire cut electric discharge machining in 1770, but it was inaccurate and rife with errors. The WEDM method, first used commercially in the 1970s, had a significant impact on the steel industry we see today. When you look at the middle of the 1980s, WEDM strategies were used in device tools. These changes increased the attraction of wire cut electric discharge machining and provided benefits over traditional machining techniques.[3]. The novel idea of production makes use of non-conventional energies. An increasing number of challenging-to-make products are being produced due to technology and industry development. Numerous industries, including nuclear engineering and aerospace, heavily utilize these items. New developments in material science have produced large-scale engineering projects using novel materials. The requirement to mill these distinctive items has given rise to nontraditional machining. When you consider how often they avoid using typical metal tools and instead employ other types of power, machining procedures tend to be unconventional [4]. Nontraditional techniques can address the problems of extreme intricacy in size and shape and a higher necessity for product surface and precision finish. Since nontraditional procedures currently have practically infinite potential beyond size-based product elimination costs, significant advancements have been achieved in recent years to increase material removal rates. The effectiveness of operations may also rise as the removal rate rises, encouraging ever-better use of unconventional techniques. [5], [6]. The first suggestions for applying electric discharges for cutting work that might be metallic were developed by Tilghman (1889). The larger delimit for the region that will exclusively relate to discharge is that it is electric with the patent that is the current application developed by Boris and Natalia Lazarenko to easily machine conductive electro-electronic materials, set out to develop a technique [7], [8].

1.2 Motivation

As a result of economic globalization, the manufacturing sector is undergoing a continuous transformation toward greater efficiency and cutting-edge innovation through adopting cutting-edge technological advances. Therefore, to keep up with the fast-paced modern market, manufacturers of auto parts need to produce their products quickly without sacrificing quality or precision. The advancement of engineering materials like superalloys, composites, and ceramics can be attributed to the discoveries made in the field of material science. Complex machine materials often require unconventional machining techniques such as electrochemical, ultrasonic, wire cutting, and electrical discharging (WEDM). The nontraditional advanced manufacturing method of wire-cut electric discharge machining (WEDM) is increasingly popular for use with strong materials. WEDM can cut through any material that is hard to cut using more traditional methods. WEDM is the most viable choice for producing the increasingly rare materials needed in high-end professional applications like aerospace and medical technology. The use of a Taguchi design of experiment and analysis of variance to optimize the material removal rate for a timing chain sprocket constructed from AISI 1045 medium carbon steel would be inspiring.

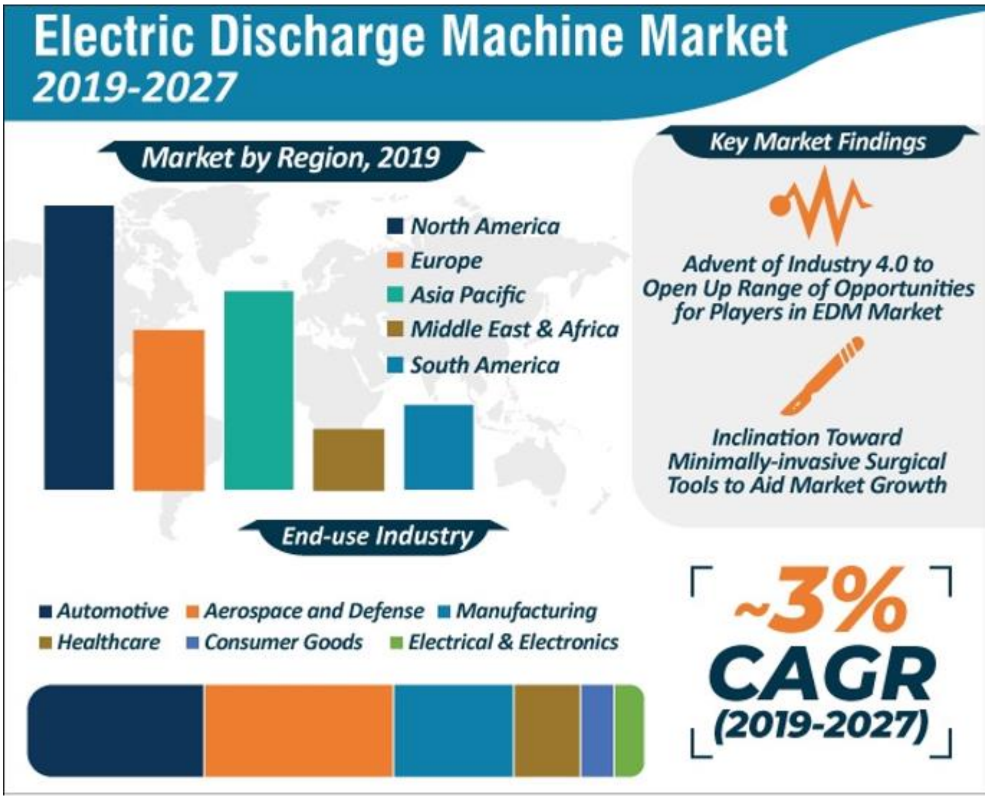

Figure 1: Main use of WEDM technology in different industries in world

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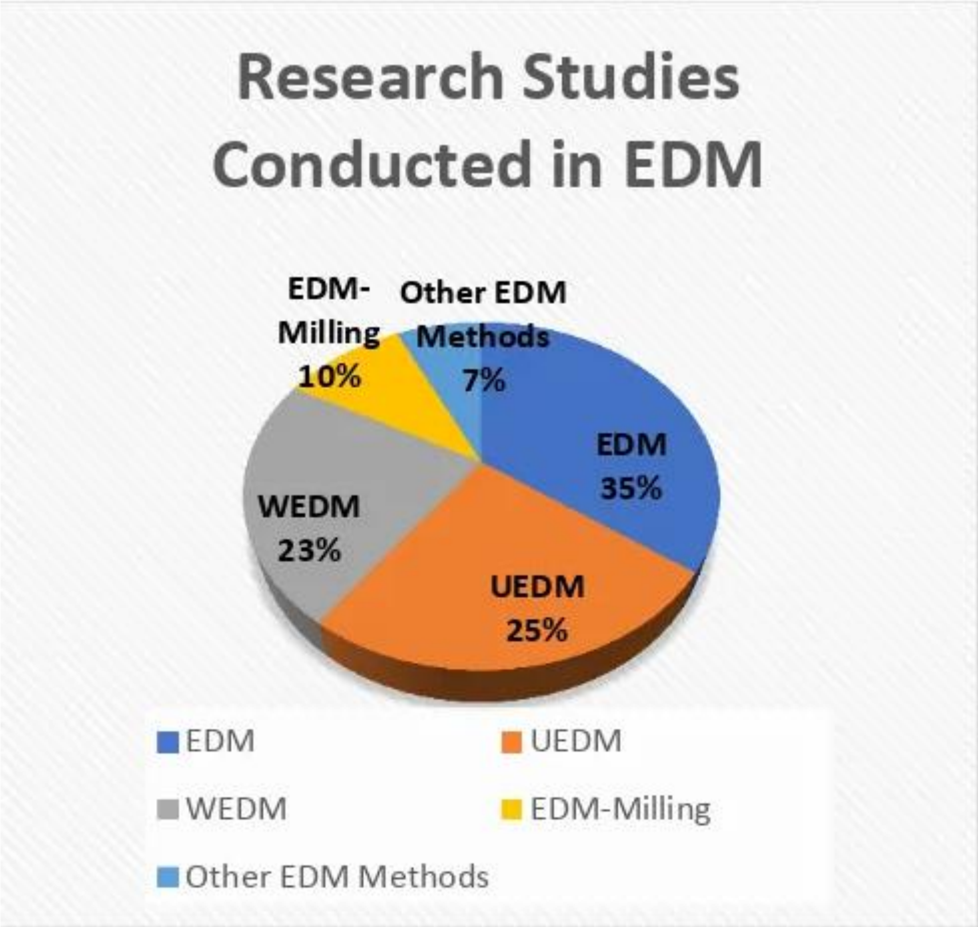

Figure 2: Research area in WEDM

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1.3 Research Problem

A sizable portion of optimization efforts have already been made on various alloys utilizing mathematical modelling, optimization with full factorial design, response surface methodology, and Finite element method. Finding the optimal input parameter values with minimal experimentation is the focus here; the goal is to make a mechanical component named a timing chain sprocket with AISI 1045 medium carbon steel suggested by the auto industry to determine the optimal ranges for the input parameters that maximize material removal rate. In order to increase cutting rates and speed up production, it would be preferable to avoid the need for a number of separate trials to determine the optimal input values and instead rely on a simple method. It's a win-win because it cuts down on production time and money.

1.4 Thesis outline

This thesis is divided into five chapters. Chapter 1 represents the introduction in which it is discussed why wire cut electric discharge machine is important in the recent manufacturing era; a brief introduction of wire cut EDM is given with its overall advantages.

Chapter 2 represents the literature review in which machining parameters and their effect on materials are discussed different optimization techniques are discussed. This chapter also includes the different responses of materials under different input control machine parameters

Chapter 3 discusses the material and methodology used in this brief research discussion on the material selection and methodology used for the material removal rate. Also discusses the number of parameters and their levels and the design of given part with complete details

Chapter 4 also reports the results obtained from the optimization technique using a higher material removal rate for the selected material. Chapter 5 represents the conclusion drawn from the results and suggests future work.

Chapter 2: Literature Review

Picking the right machining settings in WEDM is essential for getting the best machining results. In most cases, the right machining settings are determined by trial and error. However, this is no assurance that the selected machining parameters will result in optimal or near-optimal machining performance for the given electrical discharge machine and environment. In order to better the various machining response characteristics, several proposals have been made in the literature.

Nitin et al. looked at how changing input parameters in wire-EDM machining affected surface roughness and cutting speed in titanium (Ti-6Al-4V) alloy. Three inputs were used: servo voltage, wire feed speed, and wire tension. The research makes use of response surface methodology and analysis of variance [9]. Vikram. et al. examined the results of various WEDM machining input parameters on the material removal rate, surface roughness, gap voltage, gap current, and cutting rate for AISI D2 steel. pulse on time, pulse off time, peak current, servo voltage, and wire feed rate are all input parameters. Combining surface response methods and analysis of variance with the Taguchi L27 orthogonal array [10]**.**. H.singh et al. detail the ways in which the input parameters of a WEDM machine affect the rate of material removal for hot die steel AISI H-11. Pulse on-time, pulse off-time, gap voltage, peak current, wire feed, and wire tension are all input parameters. Taking things one step at a time, this research demonstrates that the pulse on time is proportional to the M.R.R [11]. For AISI D3 tool steel, G. selvakumar et al. analyzed the impact of pulse on time, peak current, wire tension, and taper angles on cutting speed, surface roughness, and the taper error. Taguchi's grey relational analysis and the Taguchi L9 orthogonal array have been employed[12]. An analysis of the effects of pulse on-time, pulse off-time, wire feed, and wire tension on the material removal rate and surface roughness of tungsten carbide was conducted by P.Haja Syeddu Masooth et al. using the Taguchi L9 orthogonal array and analysis of variance (ANOVA).[13]**.** In their study, Ravindrannadh Bobbili et al. explain how WEDM parameters affect surface roughness and material removal rate for high-strength armor steel. There are five input parameters: pulse on, pulse off, wire feed, flushing pressure, spark voltage, and wire tension. Combined with Taguchi's D.O.E. and L27 orthogonal array, an ANOVA experiment was conducted [14]**.** Various WEDM input parameters were adjusted to investigate how they impacted the time required to machine 6082 T6 aluminum, according to M. Fakkir Mohamed et al. There are three input parameters: current, pulse on time, and pulse off time. Using Taguchi's D.O.E. with L9 orthogonal array, we conducted this study [15]. As a result of experimenting with different WEDM parameters, researchers K. Satyanarayana et al. examined surface roughness and material removal rates for Inconel 600 cut by WEDM. Among the inputs are the current, the pulse on time, and the pulse off time. An L9 orthogonal array and Taguchi's D.O.E. were used for statistical analysis [16]. An analysis of the influence of WEDM input parameters on the surface roughness and kerf width of AISI 4140 was recently published by Swarup S. Deshmukh et al. This device uses pulse on time, pulse off time, servo voltage, and wire feed parameters as input parameters. Taguchi's D.O.E. with L9 orthogonal array was used in combination with Gray relation analysis, ANOVA, and regression analysis [17]**.** Was studied by Yasir Nawaz et al. how much material was removed, how wide the kerf was, and how rough the surface was of DC53 Die Steel. Pulse on time, current, time of pulse off, and wire speed are all input parameters. Along with analysis of variance (ANOVA), we also employed Taguchi's design of experiments (D.O.E.) using an L27 orthogonal array [18]**.** The effects of WEDM input parameters on the surface roughness of composite material (AL6061/SICP) were investigated by V.K. SAINI et al. pulse o n-time, pulse off-time, and current are the input parameters. ANOVA and Taguchi's D.O.E. with an L9 orthogonal array were utilized [19]**.** Powder metallurgical cold worked tool steel (VANADIS 4e) had its surface roughness investigated by D.Sudhakara et al., who looked at how different WEDM input parameters affected the material. Pulse on time, pulse off time, servo voltage, peak current, wire tension, and water pressure are all input parameters. We utilized ANOVA and Taguchi's D.O.E. using L27 orthogonal array to analyze the data [20]. Surface roughness and kerf width in stainless steel were studied by Zahid A. Khan et al., who looked at how WEDM input parameters affected the materials (SS 304). Current, pulse on time, and off time are the input parameters. Methods such as grey relational analysis, analysis of variance, and Taguchi's design of experiments using an L9 orthogonal array were employed [21]**.** The effects of WEDM input parameters on material removal rate, surface roughness, and spark gap of Inconel 825 were described by G. Rajyalakshmi et al. Input parameters are pulse on time, pulse off time, voltage, flushing pressure, wire feed rate, wire tension, spark gap, and servo feed. Taguchi's design of experiments using L36 orthogonal array, grey relational analysis, and analysis of variance were employed for this study [22]**.** Metal removal rate, kerf width, and surface roughness of AISI grade-304 stainless steel was studied to determine the impact of WEDM input parameters. voltage, pulse on time, pulse off time, and wire feed rate are the input parameters. Taguchi's design of experiments (D.O.E.) with L18 orthogonal array and analysis of variance were employed [23]. Literature analysis reveals that increasing WEDM throughput requires prioritizing the optimization of process parameters. The Taguchi Design of Experiments is the best method for discovering the optimum values of control factors and their accompanying combined effect for a specified objective. Because of its simplicity, efficiency, and reliability in reducing costs and increasing quality, the number of tests required is much reduced when compared to alternative D.O.E. procedures. Variance analysis.

2.1 Types of Electric Discharge Machining

- Die-sinking E.D.M.
- Wire-cut EDM

2.1.1 DIE-SINKING EDM

With Sinker E.D.M. Machining, two metal parts are immersed in an insulating liquid and connected to a current source, which is turned on and off automatically according to the settings on the controller. When the power is on, an electric charge builds up between the two pieces of metal. A spark will leap across the gap if the two components are brought close to within a few thousandths of an inch. Metal is melted at the point of impact due to the intense heat. Sinker E.D.M., also known as cavity type E.D.M. or amount E.D.M., involves placing a workpiece and an electrode in a tank of oil or, less commonly, another dielectric fluid. Whenever voltage is applied, an electric potential develops between the parts. The dielectric breakdown does occur in the fluid when the electrode approaches the workpiece, creating a plasma channel and a little spark. [24]. Because it is highly unlikely that all points in the inter-electrode space share the same electrical regional characteristics that would allow a spark to occur concurrently in all such spots, these sparks often occur one at a time. It's not uncommon for thousands of sparks to fly between the electrode and the work item. Whenever the electrode gap increases due to erosion of the base steel, the machine rapidly lowers the electrode to keep the process going. A few hundred thousand sparks occur every second, with the parameters carefully regulating the actual job. [25].

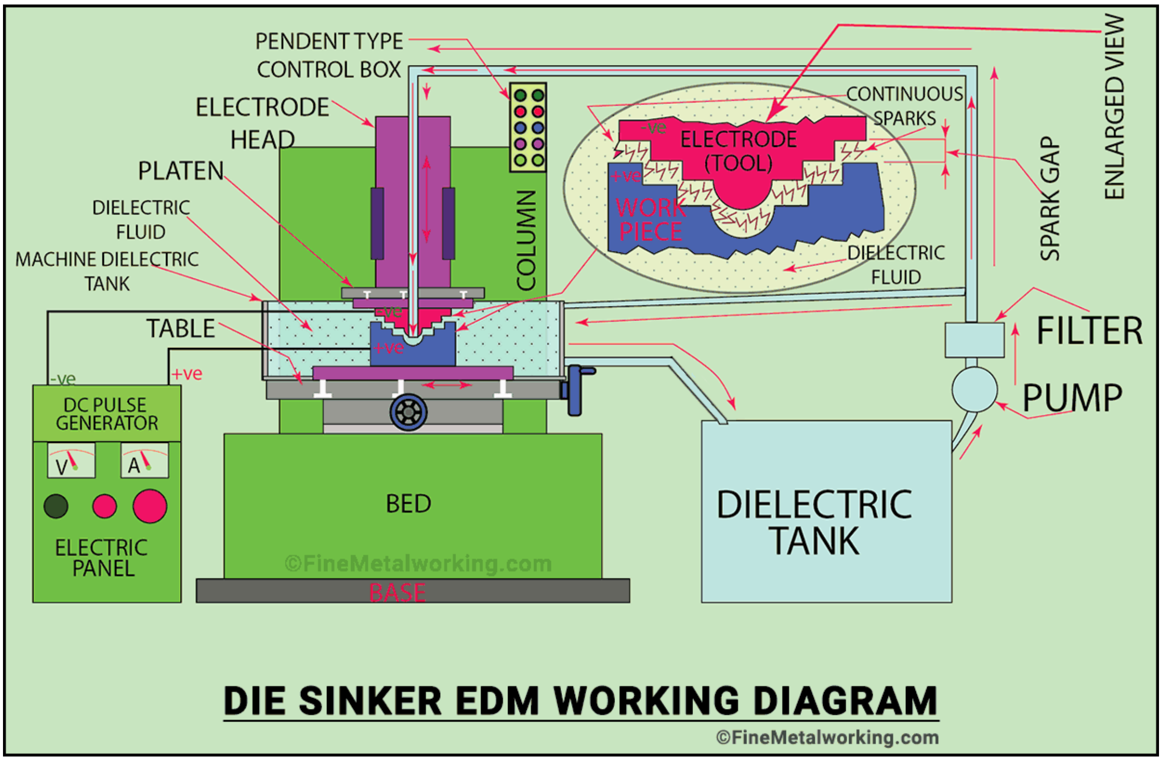

Figure 3: Die sinking machine

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2.1.2 Wire Cut Electric Discharge Machine

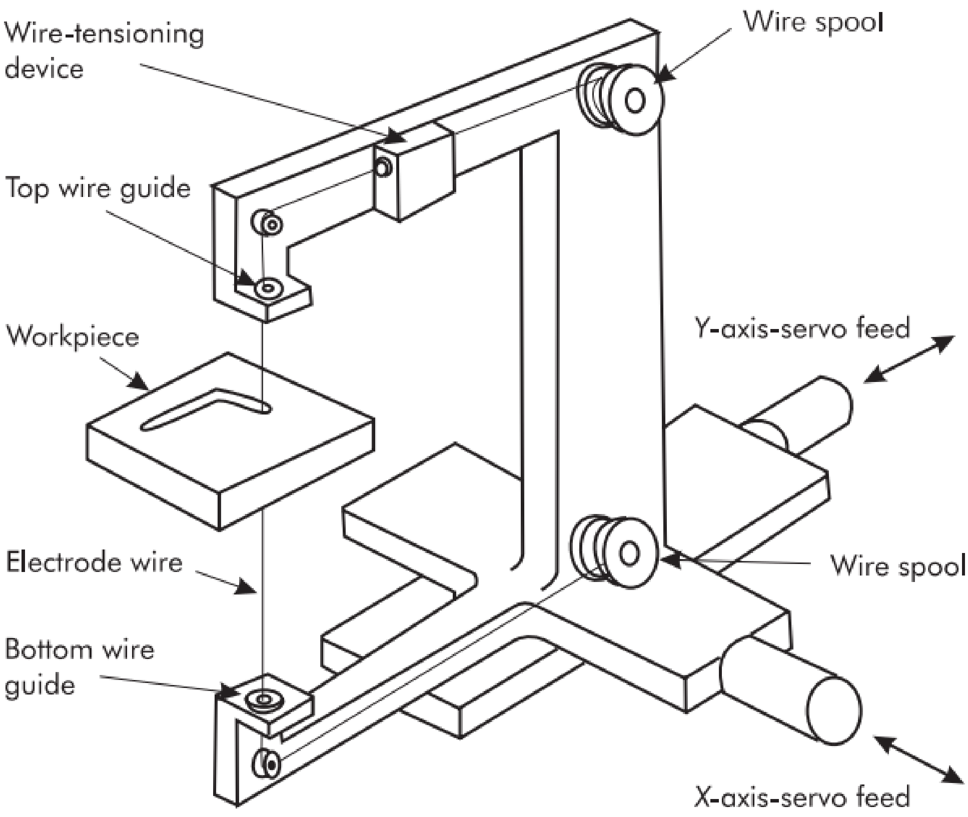

Figure 4: Wire cut E.D.M. machine (Elman. Jameson,2010)

The figure shows a wire-cutting tool with a worktable in a fixed position. Additionally, it is possible to support the work piece on an adjustable x-y table while using an electrode wire in an acceptable fixed area [26]. Servomotors, commanded by computer control handle the products that are wire-cut. A passageway for the electrode cable should always be present. Simply use an electrode cable whenever since the product is eliminated through the cable area during the sparking procedure [27]. The used cable is collected through the specific area sparking for disposal [28]. Electrical-sparking-power connections to your electrode cable as well as the elevating system for adjusting the distance that is straight between the cable guides to accommodate workpieces that are different [29]. For efficient machining, wire-cut operations, the associated electricity must be clean. A dirty contact will cause machining dilemmas. The wire that is at the top is usually adjustable for the workpiece. The guide at the top of the elevating system must be set precisely [30].

2.2 Wire Cut Machine Structure

Initially designed as open-style constructions, wire-cut machines were introduced. The tools that were accessible at the time were used to construct these devices. Numerous changes have been made to computer control. It was common practice to manually insert machining programmes. Due to the necessity to create intricate shapes without using the machined electrode required for die-sink devices, wire-cut machines have been developed.[31]. E.D.M. devices that are wire-cut A development is major for all through-hole-machining applications. Nevertheless, because the machining was achieved in the great outdoors, users were concerned about the electrically charged wire and the liquid used as the dielectric fluid and thrown on the device and the space around it. Fig.5 illustrates an open-style wire-cut machine. Engineers had eliminated these difficulties by setting up a defensive top of the wire-feed device and a splash across the workshop. This design sets a standard for wire-cut devices. Because the process is wire-cut, it was found that raising the dielectric-flow stress and cost also raised the machining speed. It was impractical to use impact shields to restrict the fluid due to the increase in the dielectric-flow pressure and costs [32].

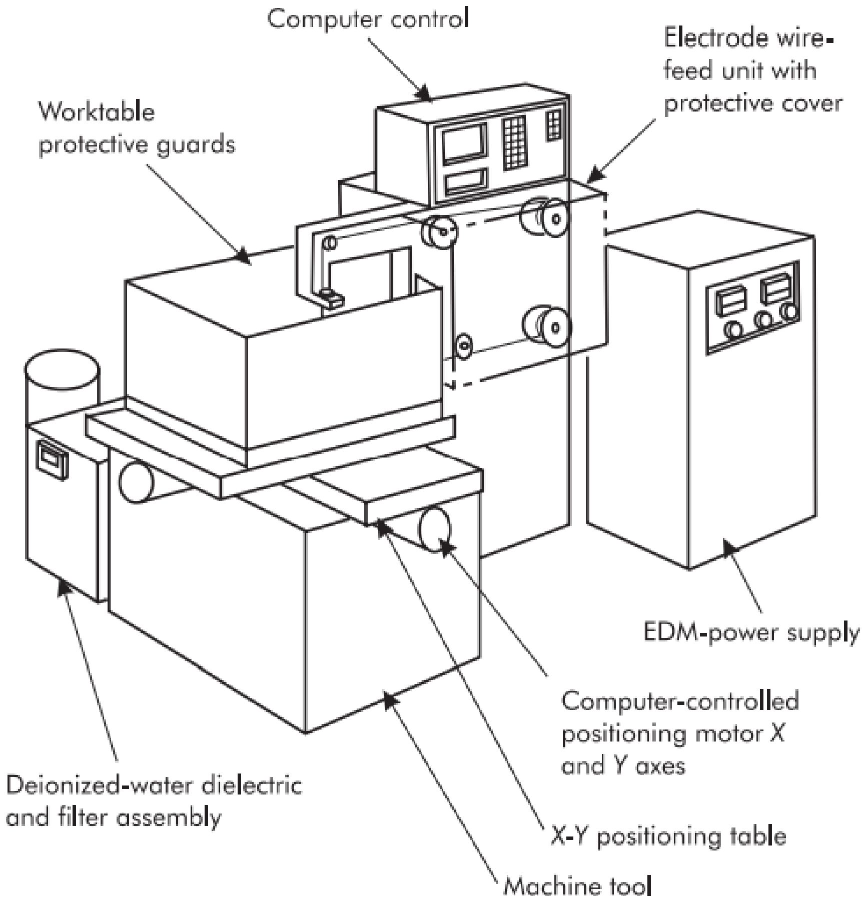

Figure 5: Open style wire cut machine (Elman. Jameson,2010)

A machine that is enclosed in the style originated. Fig.6 illustrates this update.

The closed wire-cut machine shields electronic components from contact with dielectric fluid. The wire-feed unit and continuous workshop are accessible only through sealed doors. For seeing the workpiece during the sparking phase, the work area door typically has a watch screen. But because so many fluids are flowing on the watch glass, it is difficult to perceive the actual machining using the high dielectric-movement speeds. The workpiece's surface extends to the wire's course at the top. The gadgets could sustain harm in a collision. Major components used in diesinker devices and wire-cut equipment are similar in description, although their designs differ significantly [33].The wire-cut mechanism is entirely under the computer's control. Through digital control, manual placement is possible for installation activities. A review system that controls all axes informs the computer connected to it of the position of each drop [34].

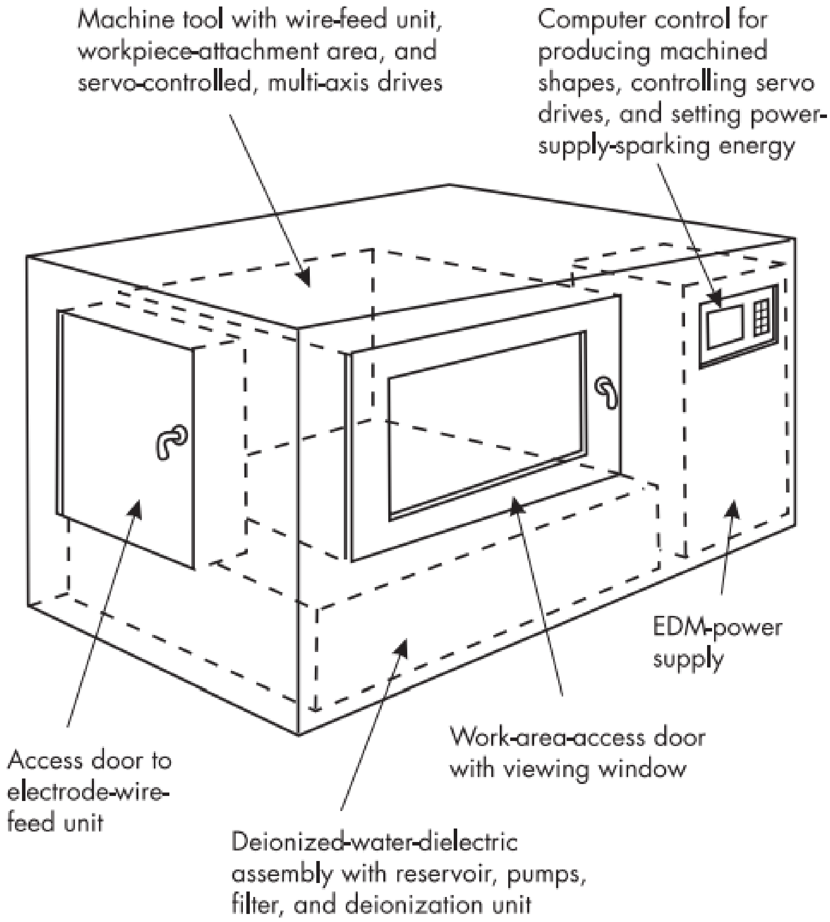

Figure 6: Enclosed style wire machine (Elman. Jameson,2010)

Manufacturers compete to give the most accurate machining processes possible by developing Methods for monitoring that optimally integrate axis computer and motor control. The wire-feed mechanism is built into the device tool as well. Because it travels through the sparking region, this unit determines the traversal speed of the wire. If the wire moves too slowly across the area, the constant sparking will wear out the cable until it snaps. [35]. The cable's movement through the sparking zone should be delayed until the area has cooled down. The wire-feed device's dual roles of regulating wire-crossing velocity and maintaining electrode cable tautness and straightness are mutually dependent. The machine servo was not properly tensioned. [36].

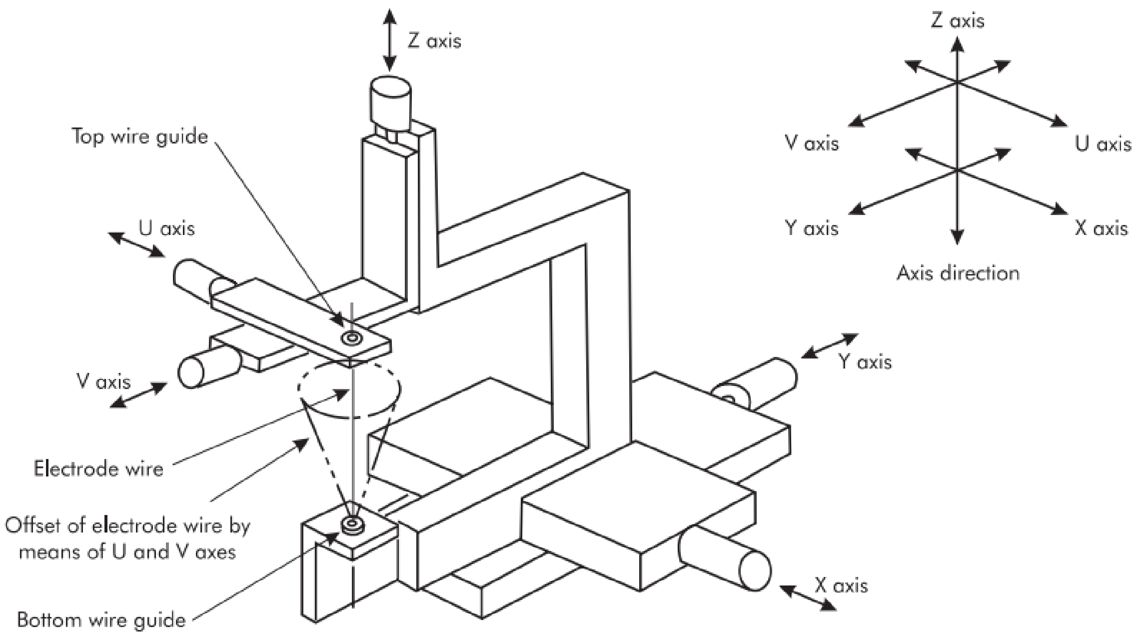

Figure 7: Five axes wire cut machine design (Elman. Jameson,2010)

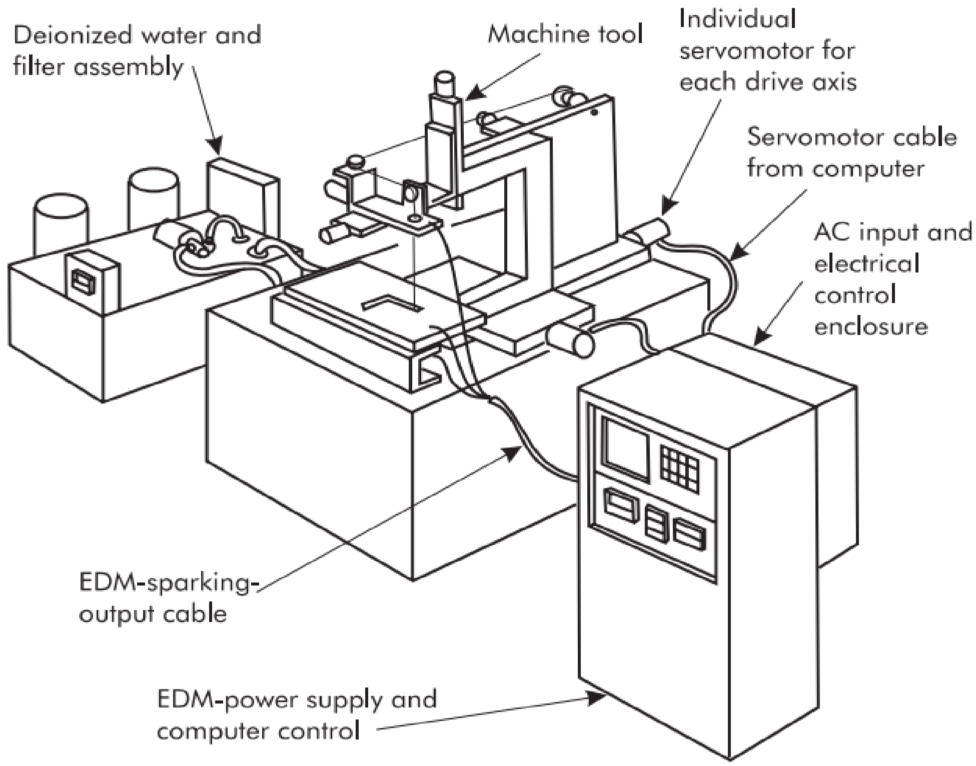

Figure 8: Wire cut machine assembly (Elman. Jameson,2010)

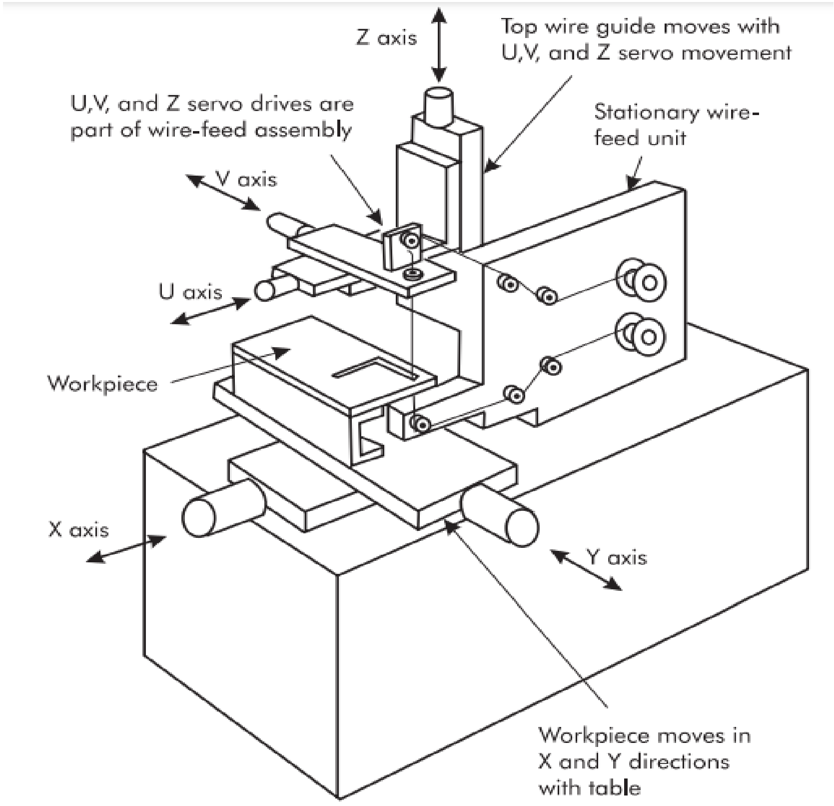

Figure 9: Moving work piece wire cut machine (Elman. Jameson,2010)

The X-Y orientation table shown in Fig.9 is an example of a design that can be used to relocate the workpiece. During taper-machining processes, the electrode cable remains in one place but can be displaced in U and V directions courtesy of a wire guide at the top. [12]. An alternative layout that carries the workpiece and electrode cable The fashion is depicted in Figure 11. Again, the top connector incorporates the U and V axes to give you the cable misalignment needed for taper-machining [37].

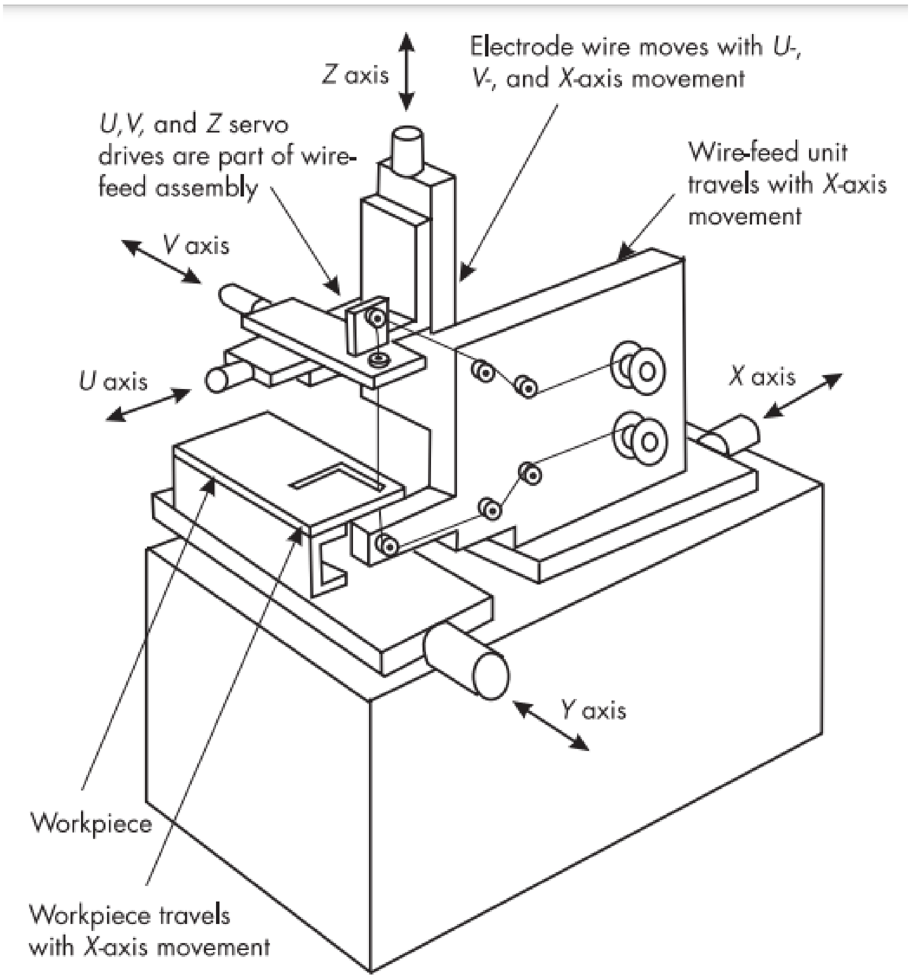

Figure 10: Moving work piece and electrode wire cut design (Elman. Jameson,2010)

2.2.1 Dielectric-fluid and Filtration Unit

After the water is returned from the wire-cut dielectric system, it must undergo a filtering process to remove the sparking leftovers. In order to be used as a dielectric in a water-emitting diode (WEDM), the water must undergo additional processing beyond purification[38]. Even while de-ionized water is initially an electrical insulator, it quickly transforms into a conductor when exposed to an electric spark and allowed to dissolve solids. Water is de-ionized and returned to a usable purity level by passing through a resin tank, which removes any remaining dissolved materials. [39].

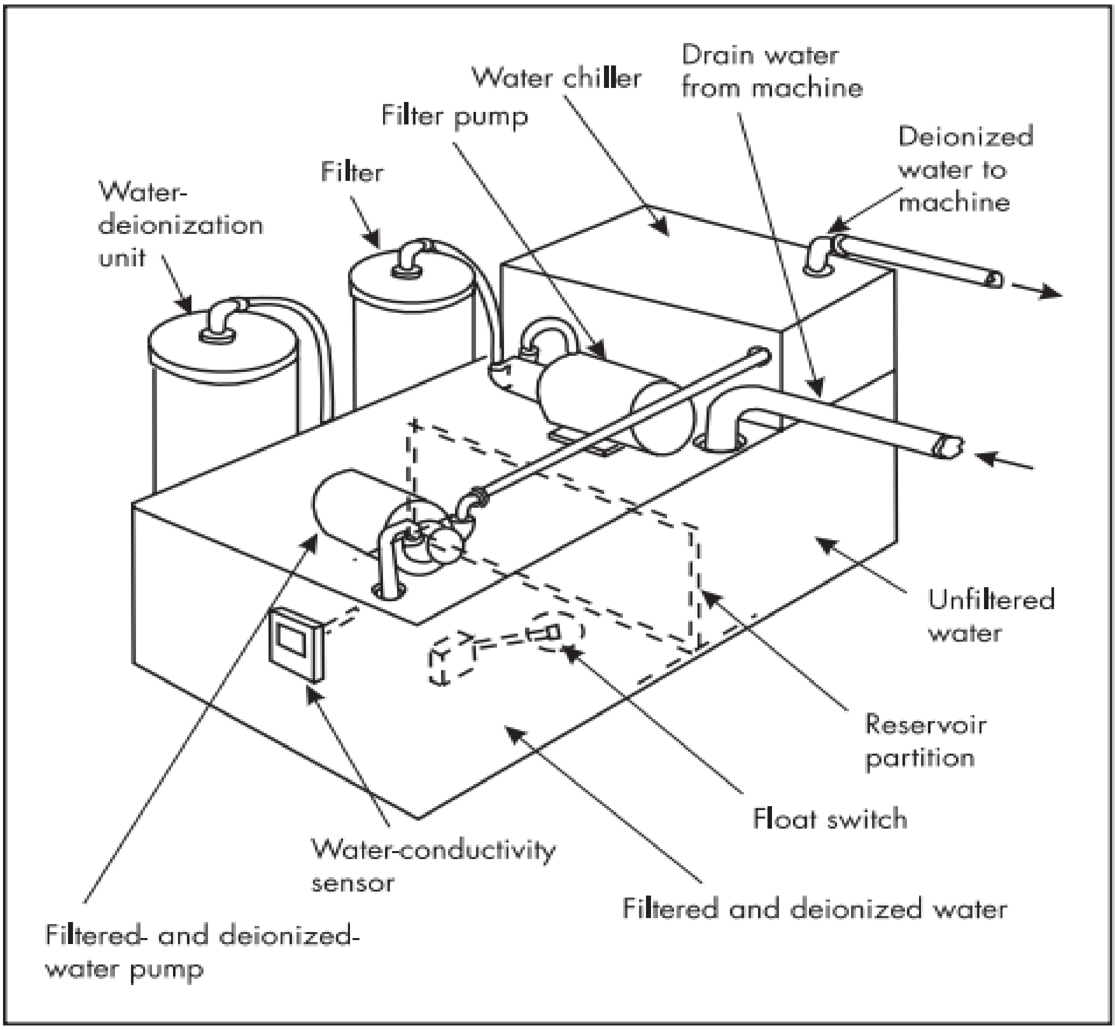

Figure 11: De-ionized water dielectric assembly (Elman. Jameson,2010)

The machine tool's used water is recycled into the dielectrically unfiltered water supply. Untreated and de-ionized water is kept in different compartments within the dielectric tank. The solid WEDM material is removed by pumping water from the unfiltered reservoir through the filter. Finally, the water is pumped into the filtered and de-ionized water storage tank after passing through the resin tank. A sensor is built into the de-ionized water tank to track its electrical conductivity as it sits in the tank after being filtered and de-ionized. If the electrical conductivity changes to a dangerous degree, a warning appears on the screen. Figure 11: Dielectric stack made of de-ionized water. Even if an adequate electrical-conductivity value is acquired, it may be too late to begin a WEDM-sparking cycle. De-ionized water storage tanks typically have float switches. When the water level drops below the switch's threshold, an alarm goes off, and a warning may appear on the screen. It may not begin a machining cycle if the low-water limit is flashing red. During machining, water evaporates and is lost as mist [11]. The factory's water supply could be used for replacement water, but only after the contaminants have been purified. Before installing wire-cutting machines, the factory's water quality should be evaluated. It is recommended that the findings of the water tests be addressed with the maker of the equipment. In most cases, a wire-cut dielectric system includes a water-cooling unit. The temperature of the water-dielectric fluid has a significant impact on the efficiency of wire-cut machining [40]. The rate of machining slows down as the water temperature rises. It is important to strictly adhere to the water-dielectric fluid manufacturer's recommended operating temperatures [41]**.** Some wire-cut machines require the use of hydrocarbon oil. Filtration considerations for oil-using machines are the same as those for diesinker machines. Sparks should never be shown off in public. Most manufacturers advise against combining hydrocarbon oil and de-ionized water in a single appliance [42]. Wire-cut machining can sometimes benefit from having the workpiece submerged. Since it is difficult to drive the dielectric fluid into the kerfs slot, submerging the workpiece is a viable option when it is too large or has a curved top surface. We need a work tank to hold the fluid to submerge the work component.[43], [44], [45].

2.2.2 Material Removal Process

The WEDM procedure eliminates the product through thermal power, indicating that the temperature has been roofed. The temperature throughout the spark is high [46],

[47]. One ampere equals 6.25 billion electrons going to a given point in one second. This is how many electrons pass in one second for each ampere of machining electricity [27]. A proven fact that is interesting to consider about the movement of electricity in the E.D.M. spark is that electricity travels at nearly the rate of light, which travels at a rate of 186,000 kilometers (299,274 kilometers) per second. For a place of reference, electricity and light travel at a speed of approximately seven times around the global world during the equator in one single second. Since the space is in a range of.001–.004 in. (0.025–0.100 mm) [48].The movement of electricity over the sparking gap must be instantaneous [49]. Ionization of the dielectric fluid starts the flow of electricity between the electrodes and the workpiece. Electricity is the flow of electric charges. Figure 12 illustrates the movement of electrons through the electrode by having adversely charged polarity towards the workpiece that has a positively charged polarity[50]. During each spark, millions of electrons flow at a speed that is approximately that of the electrons that travel easily through the column that is ionized of fluid.

Nevertheless, the area of the workpiece can be a barrier [51]. As electrons bombard the ongoing work piece, releasing their power in the form of temperature, this vaporizes the ongoing work piece area into a cloud. Because the workpiece has a positive polarity cloud, the vapour can be completely charged. This positively charged vapour cloud is drawn to the negatively charged electrode. At the right time that the vapour cloud is in transit toward the electrode, the sparking electricity is switched off. This eliminates the vapour cloud's attraction that is electrical to the electrode. The dielectric fluid ionizes, and the vapour cloud is cooled to form an E.D.M. chip.

Figures 12 through 15 illustrate this procedure. The bombardment destination using the ionized line of dielectric fluid is, the truth, more complex than described. Through the spark, electrons are freed and drawn to the positive polarity. The atoms from where the electrons have been removed become ions, which is good because they are interested in the polarity that is negative [10]. Fig.16 illustrates the motion of electrons and good ions in the spark-ionized column whenever an electrode has a negative polarity. When working with a negative electrode, two main actions take place. Negative electrons bombard the good workpiece surface, and good ions bombard the electrode surface that is negative. Fig.12 illustrates the movement of electrons through the electrode by having an adversely charged polarity towards the workpiece with a positively charged polarity. During each spark, millions of electrons flow between your electrode and workpiece at a speed that is approximately the same. The electrons travel easily through the column that is ionized with fluid, but the area of the workpiece can be a barrier. As electrons bombard the ongoing work piece, releasing their power in the form of temperature, this vaporizes the ongoing work piece area into a cloud. Because the workpiece has a positive polarity cloud, the vapour can be completely charged. This positively charged vapour cloud is drawn to the negatively charged electrode. At the right time that the vapour cloud is in transit toward the electrode, the sparking electricity is switched off. This eliminates the vapour cloud's attraction that is electrical to the electrode [52]. The dielectric fluid ionizes, and the vapour cloud is cooled to form an E.D.M. chip.

Figures 13 -16 illustrate this procedure. The bombardment destination using the ionized line of dielectric fluid is, the truth, more complex than described. Through the spark, electrons are freed and drawn to the positive polarity. The atoms from which the electrons have been removed become ions, which are good because they are interested in the negative polarity. Figure-17 illustrates the motion of electrons and good ions in the column that are spark-ionized whenever an electrode has a negative polarity. When working with a negative electrode, two main actions take place. Negative electrons bombard the good workpiece surface, and good ions bombard the negative electrode surface [53].

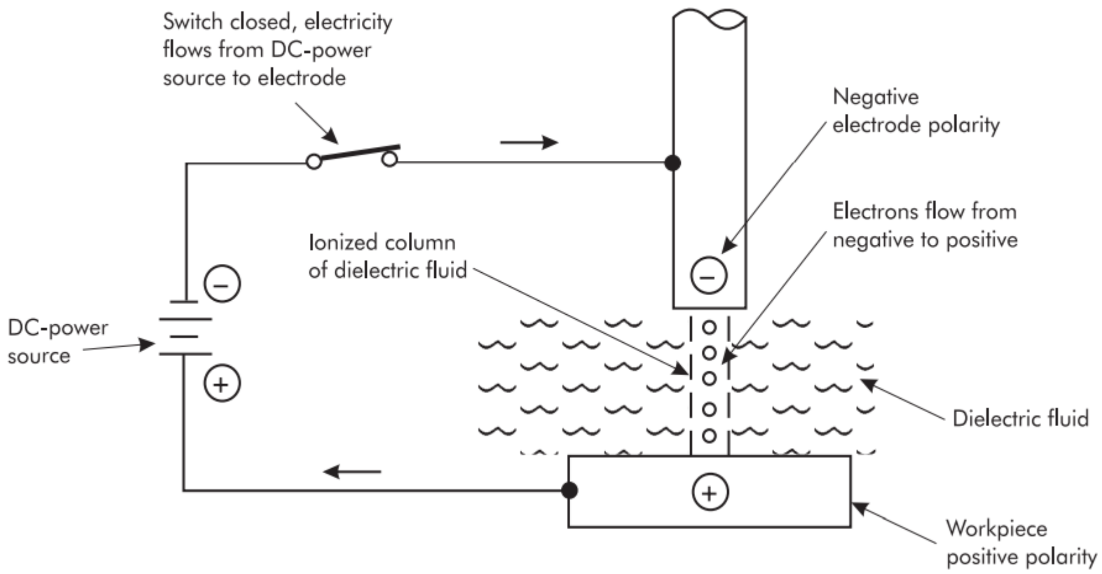

Figure 12: Spark electron flow with negative electrode polarity (Elman. Jameson,2010)

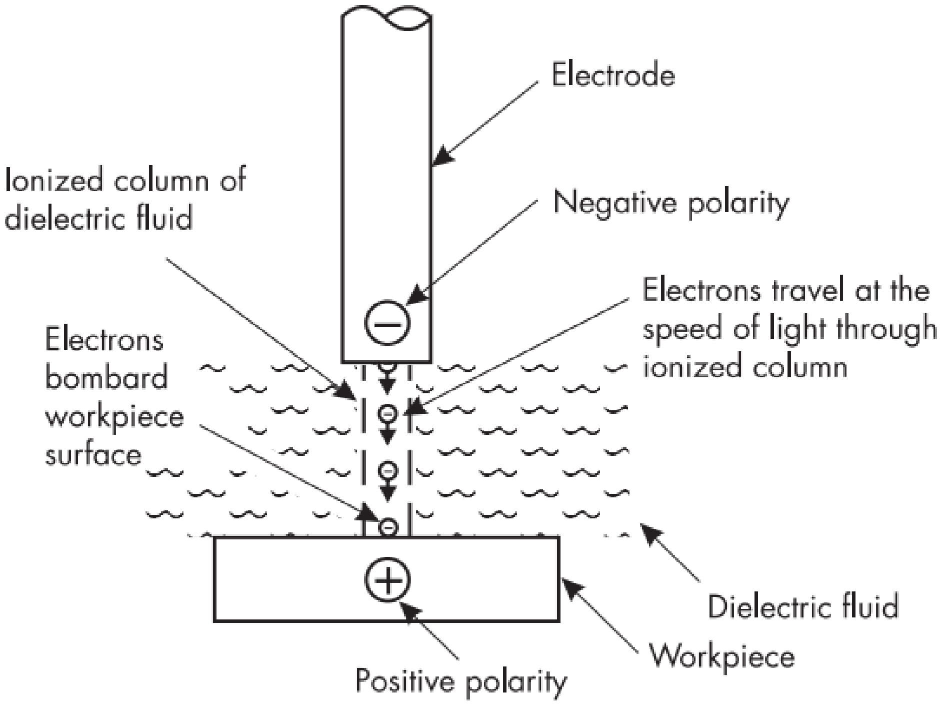

Figure 13: Electron's bombard on work piece surface (Elman. Jameson,2010)

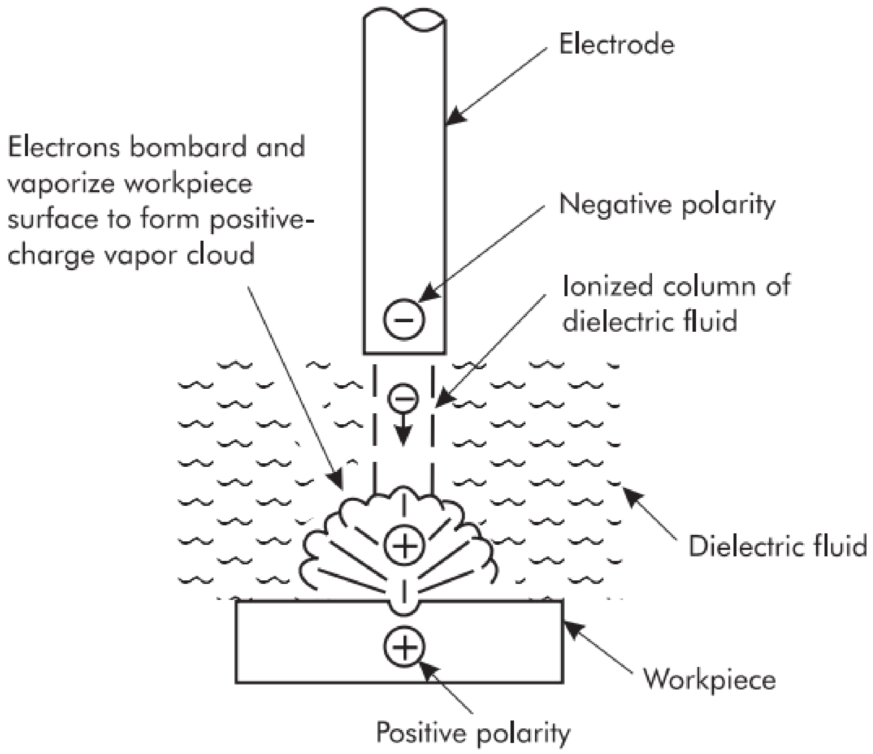

Figure 14: Electron bombardment produces a vapor cloud (Elman. Jameson,2010)

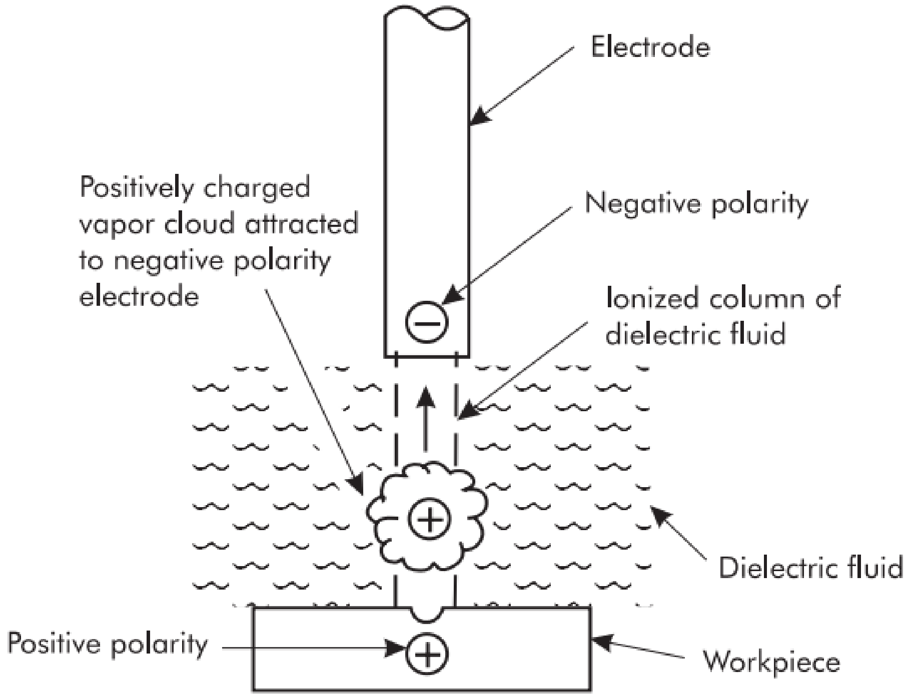

Figure 15: Positive vapour cloud attracted to negative electrode (Elman. Jameson,2010)

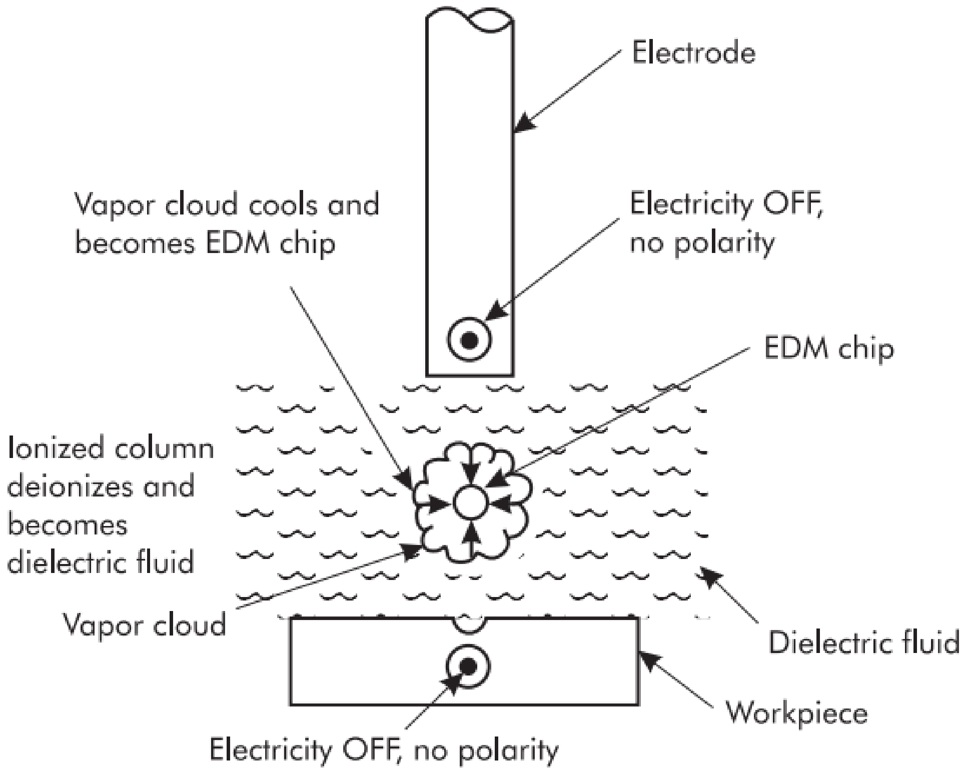

Figure 16: Spark off; vapour cloud cools to form a chip (Elman. Jameson,2010)

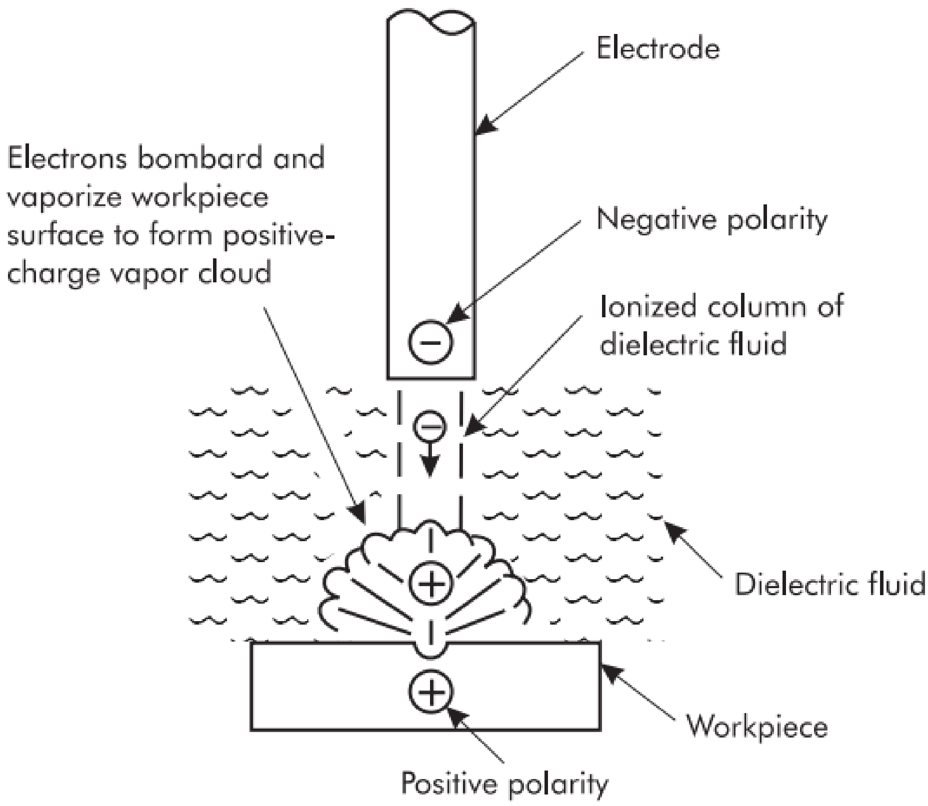

Figure 17: Electron and positive ion movement with negative electrode polarity (Elman. Jameson,2010)

The most notable is that as a result of this bombardment, material from both the electrode and workpiece will be vaporized with each spark figure-18 through figure-21 illustrate this bombardment, the clouds which are vapour and the EDM-chip development [27], [53]. Fewer ions, which may be electrons, reached the area of striking while sparking. These electrons are the primary source for WEDM material removal [54]. These clouds are contrary vapour polarities, so they are enthusiastic about each other. The clouds, which are vapour combined, whenever electricity that is sparking is deterred, they cool to produce chip [55], [56]. Illustrations, until now, have shown a negative electrode and a bombardment that is an electron of the workpiece for item elimination.

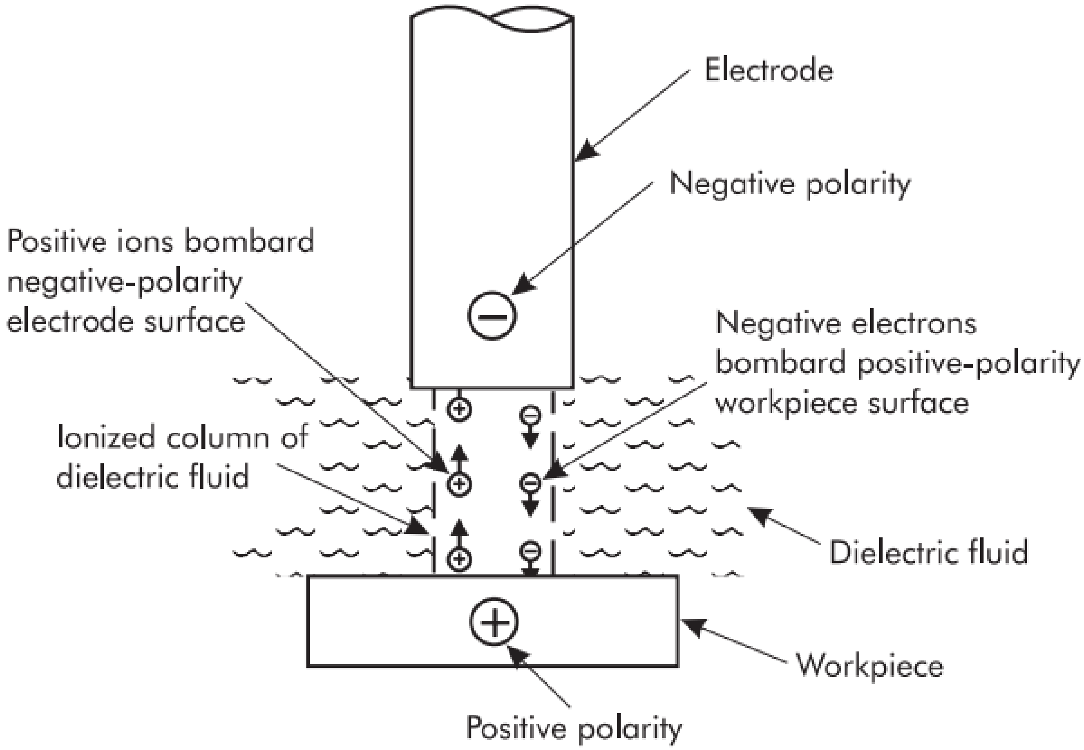

Figure 18: Electron and positive ion bombardment (Elman. Jameson,2010)

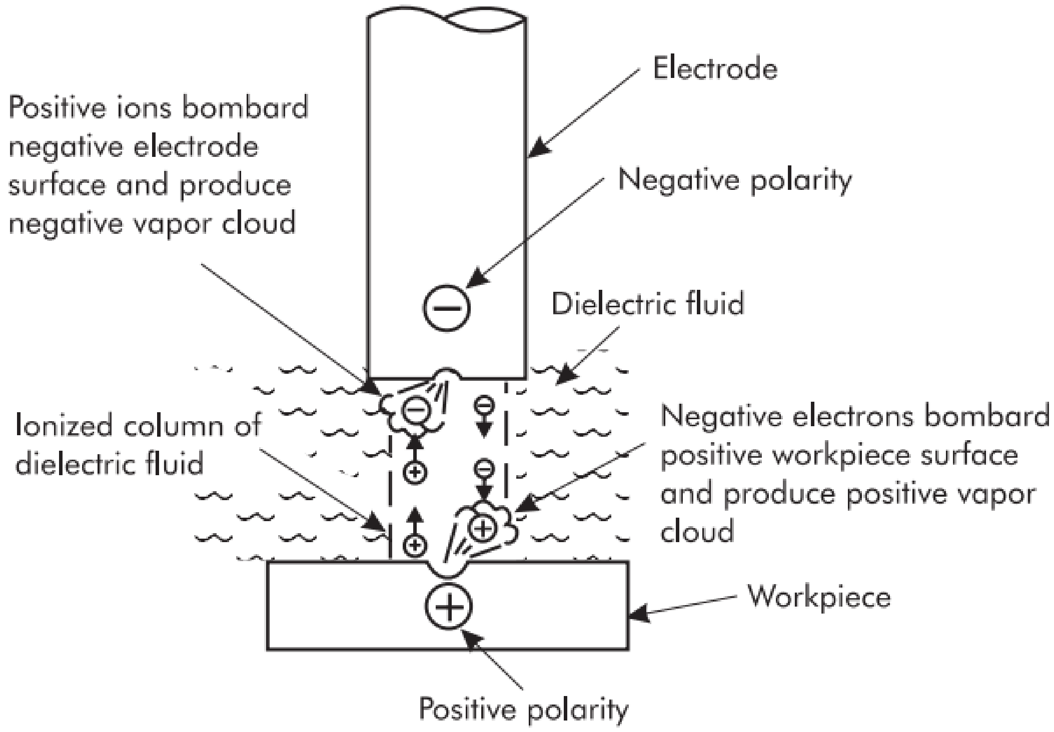

Figure 19: Electron and positive ion vapour cloud (Elman. Jameson,2010)

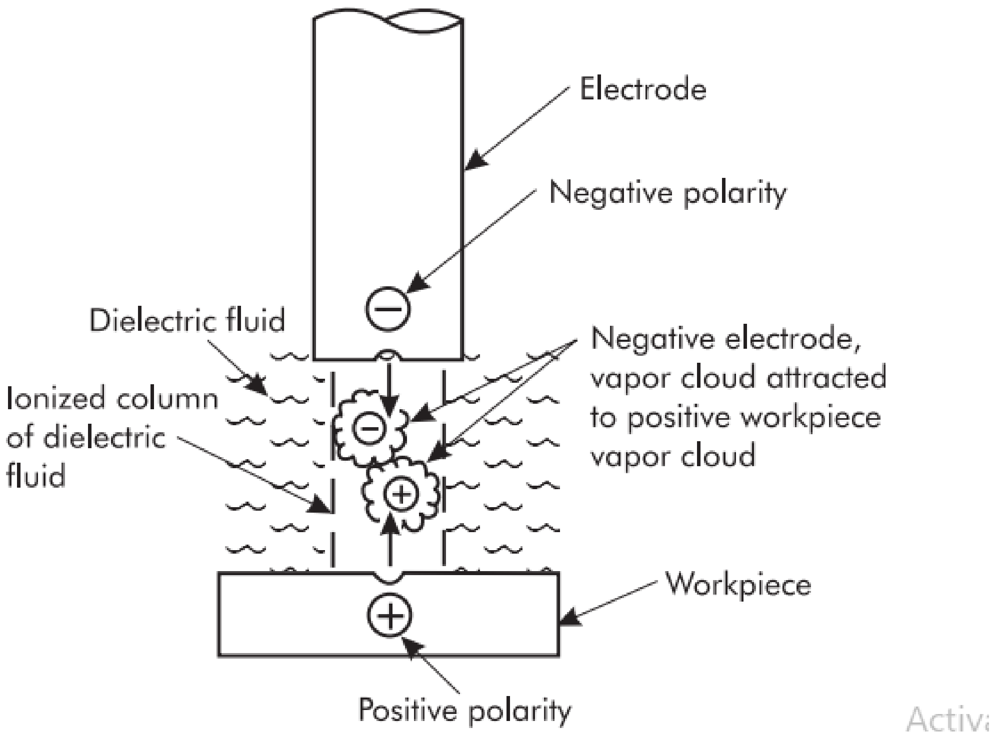

Figure 20: Opposite polarity vapor clouds attract (Elman. Jameson,2010)

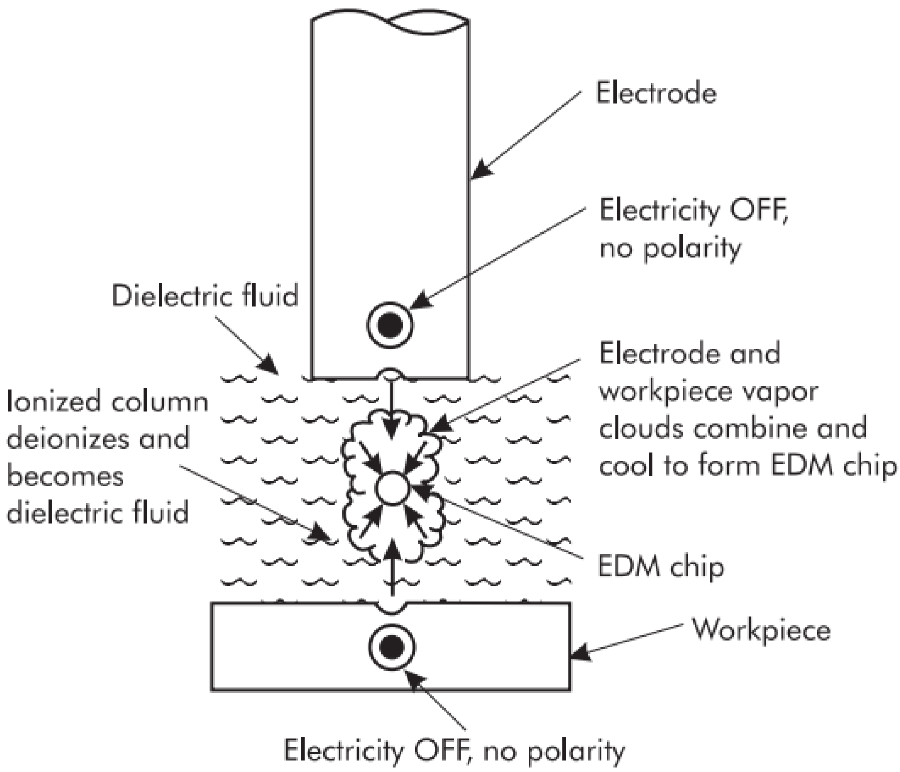

Figure 21: Vapor clouds combine and cool to form an E.D.M. chip (Elman. Jameson,2010)

WEDM researchers have determined that an electrode that is good is advantageous for reducing electrode usage or supplying a more stable servo when working with specific electrodes and work piece materials. Fig.21 illustrates product treatment utilizing good electrode polarity in the form of positive-ion bombardment [57].

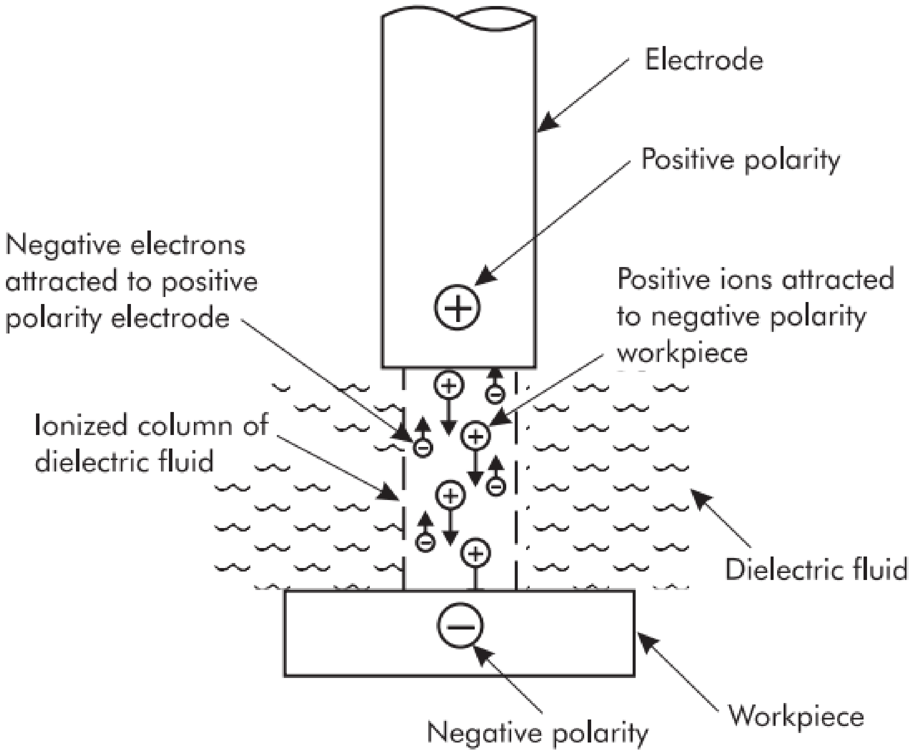

Figure 22: Material removal with positive electrode polarity (Elman. Jameson,2010)

Wire-cut device electrode polarity is hardly ever changed and really should just be done based on the suggestion associated with the device maker. Some wire-cut machines may not have the choice of changing the electrode polarity. Wire-cut-machine manufacturers generally provide the electrode polarity that produces the utmost material-removal speed since electrode material and fabrication costs are not the main aspect of machining operations. The de-ionized water's dielectric power should be carefully considered for wire-cut-machining operations. The machine needs to be operated just in the range that is allowable in quality, as specified by the manufacturer. If the water is allowed to be conductive, it will not ionize properly. This can have an influence that is detrimental to servo steel and security removal prices. The water's dielectric energy changes because the d-ionized water passes through the sparking location. Reusing the d-ionized water without purification and reprocessing through the d-ionizing resin sleep is not suggested. Under normal machining conditions, the electrode cable continually passes through the traversing workpiece to create the needed shape. Because the workpiece sparks through the electrode wire device, a slot is produced [58]**.** The size of the spark is controlled by the energy that is dielectric with regard to the fluid. Should the workpiece be allowed to stop the traverse and dwell in one single location while sparking, electricity is ON; a family member line will soon be machined into the workpiece surface. The reason behind this machining might be explained by comparing the exact distance between the spark and the dwell period of the workpiece. Figure 23 illustrates the slot produced by sparking during normal machining. Under the conditions illustrated, ionization of this dielectric fluid will create a spark that is the same for the frontal and radial overcuts, as the workpiece traverse rate is adjusted to achieve the best effectiveness in sparking.

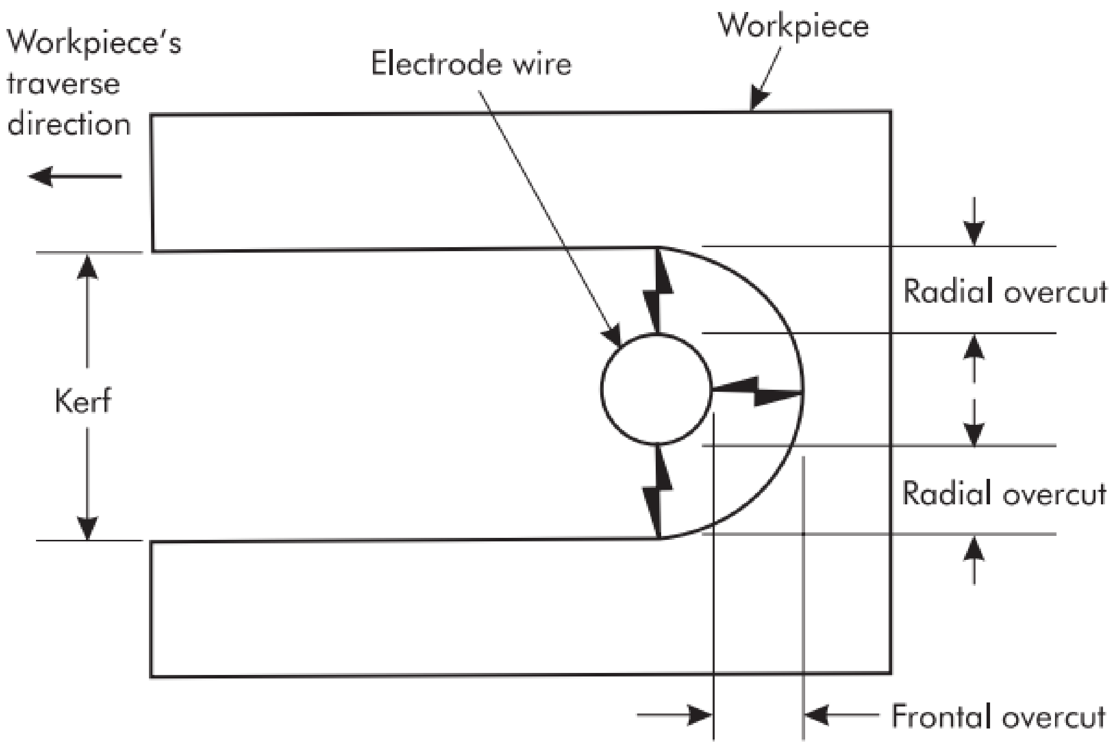

Figure 23: Wire cut slot producing normal machining (Elman. Jameson,2010)

Enlargement of the slot at the true point of workpiece dwell is explained by the ionization point of the dielectric fluid. There is a dimension involving the electrode and workpiece at which the fluid is dielectric, and a spark does occur. The spark during normal wire-cut machining size is slightly compressed. Traverse rate modified to ensure that material is always provided to the electrode for efficient sparking. If the traverse is stopped, the workpiece is allowed to dwell in a single spot aided by the sparking electricity. The sparking continues until the spark size reaches the normal over-cut measurement. This causes an expansion of the spark over cut at the true point where the dwelling of the workpiece has occurred. Although tiny in-depth, this enhancement seems to be a line machined into the workpiece area. Radial overcutting is slightly paid off, although the workpiece will be traversed. The traverse rate decreases at the right time the slot walls are exposed to sparking, which in turn causes a small decrease in the radial overcut measurement compared to the spark that is normally cut. Whenever work piece traverse is stopped utilizing the sparking electricity ON, sparking continues and devices both the frontal and cut that is radial-over towards the normal spark-length over cut measurement [27], [59].

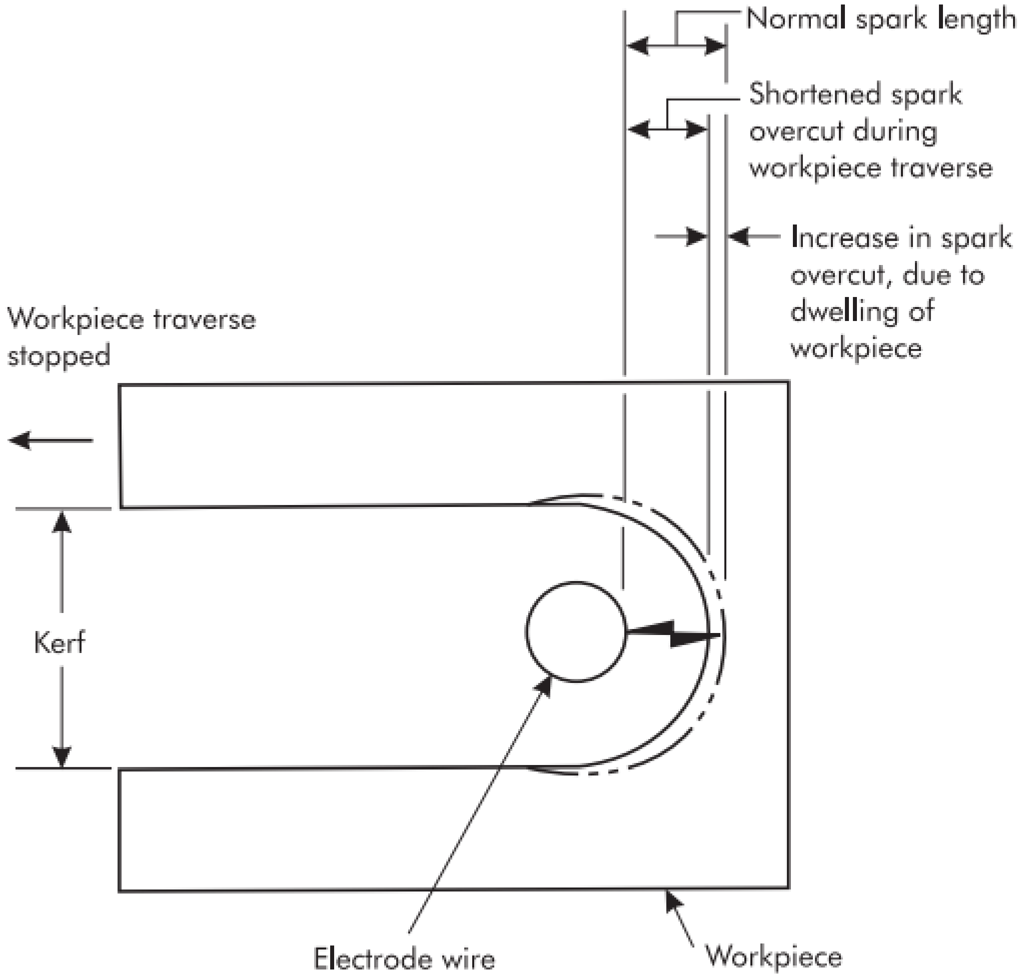

Figure 24: An increase in overcutting with traverse stopped and sparked electricity (Elman. Jameson,2010)

2.3 WEDM Process Parameters

Pulse on Time:

Measured in microseconds (s) and shown as a pulse on time. At this point, a spark will have appeared between the electrode wire and the workpiece. At this stage, the electrodes are subjected to a voltage (V.P.) [60].

Pulse off time:

There will be no electric discharge between the workpiece and the wire electrode since no voltage is applied during this period. A decrease in discharge potential causes wire breakdown, decreasing cutting accuracy. [61].

Arc Gap:

The arc area represents the working electrode's separation from the other electrode during the procedure. A more appropriate name for this space may be the "spark room." A servo system is in charge of keeping spark gaps in good condition [62].

Discharge current (current Ip):

For a given pulse on time, the peak current, denoted by I.P., is the highest current that may flow through the circuit. Current is quantified in amperes. This parameter may calculate how much WEDM uses energy [63].

Duty cycle (τ):

This metric, which measures the on-time of a process concerning its total running time, is calculated by dividing the on-time by the running time (on-pulse off time)[64].

Voltage (V):

It affects your material reduction rate and the number of periods in which you are permitted to do so, and its magnitude can be measured in volts [1].

2.3.1 WEDM Response Parameter

Material Removal Rate:

The M.R.R. is normally expressed as the volume of the eliminated material per unit of time. Material removal rates have drawn attention because the M.R.R. shows how fast machining is [64]. This will be the response factor in this study; we will observe the effect of input parameters on material removal rate.

2.4 Research Gap

The majority of earlier investigations either concentrated on one material attribute at a time or one process parameter at a time. There is also very little literature on how input parameters are used at the same time in real-time fabrication, which is important because many process parameters are used at the same time in rapid prototyping. Therefore, studying the effect of using simultaneous parameters on material properties is crucial to better understanding WEDM.

1) From the literature review, it was found that most authors have used several methods of optimization, including optimization through mathematical modelling, full factorial design, response surface methodology, and the Finite Element Method, but in this work, parametric optimization with Taguchi D.O.E. is used, and for validation, analysis of variance is used.

2) As evident from the literature, the combined effect of different WEDM parameters has not been studied extensively, so we decided to use the Taguchi design of experiments to investigate the impact of various WEDM parameter combinations.

3) The majority of studies examined the impact of WEDM parameters on materials and alloys, titanium alloys, hybrid aluminum composites, etc. Previous studies show that parametric effects change when providing different working materials. So, a study of the material removal rate for timing chain sprocket gear made of medium carbon steel, AISI 1045, was chosen.

This study is unique from other studies done previously in the following regards:

- The parameters selected for our study include Current, Voltage, and Pulse-on - Time.
- We looked at how Peak Current, Voltage, and Pulse-On-Time worked together to affect how quickly medium carbon steel, or AISI 1045, was removed from the sample.
- The Taguchi Design of Experiment (D.O.E.) L9 array has been employed in this investigation with an analysis of variance to come up with a smaller number of experiments and to get an optimized combination of WEDM parameters for a higher material removal rate.

- This study aims to achieve optimal parameters using different levels of input process parameters, providing a better understanding of the significance of different input parameters with the help of statistical analysis.

Chapter 3: Materials and Methods

Medium carbon steel (1045) was employed in this study because of its high firmness, high hardenability, and high machinability. When AISI 1045 is melted, it retains the sway qualities of the standard form. The best formability is found in AISI 1045 metallic in its standard or heat-treated state. Various actions can be done to the workpiece by following the manufacturer's guidelines for inputs, tool types, and speeds. To do this, we'll fabricate a mechanical component called a "TIMING CHAIN SPROCKET" and measure the pace at which we can remove material under various settings. When the engine is running, the timing chain sprocket coordinates the movement of the crankshaft and camshaft(s) so that the valves can open and close in time with the combustion process. If it breaks, the inlet and exhaust valves won't open and close at the right times, leading to higher fuel consumption and other problems. Table 1 displays the chemical characteristics of AISI 1045 medium carbon steel, while Table 2 displays its mechanical characteristics [65]**.**

Table 1: Chemical properties for 1045 medium carbon steel

Component	**Percentage (%)**
Carbon (C)	0.420 - 0.50 %
Iron (Fe)	98.51 - 98.98 %
Manganese (M.N.)	0.60 - 0.90 %
Phosphorous (P)	≤ 0.040 %
Sulphur (S)	≤ 0.050 %

Table 2: Mechanical properties for 1045 medium carbon steel

BH	163
HR	84
Tensile strength, Ultimate	565.004 MPA
Tensile Strength, Yield	310.001 MPA
E	200.005 GPA
K	140.006 GPA
V	0.290
G	2.1GPA

Chapter 3: Methodology

3.1 Taguchi Design of Experiment

Genichi Taguchi developed analytical approaches for improving product quality; these have found a new use in engineering advertising and promotion. Expert statisticians have praised Taguchi's methods for their efficacy in achieving their goals, and they particularly admire the designs Taguchi created to examine sources of variance. After WWII, Japan's manufacturing sector had been trying to make ends meet on a meagre budget. If it hadn't, the United States might not be here today, much less thriving. Taguchi's work is largely responsible for this. Taguchi's cost-saving innovations completely changed Japanese manufacturing. Like many other engineers, he realized that environmental factors, such as noise, may affect every step in the manufacturing process. Taguchi, however, was aware of techniques for pinpointing the origins of noise and thereby identifying the factors most responsible for variation in manufactured goods. His advice has been copied by prosperous factories worldwide since it allows for higher quality manufacturing at lower costs.

3.1.1 Process optimization

Controlling a method to maximize a selected set of parameters without going against a constraint is an example of process optimization. Expense reduction, scope expansion, and increased efficiency are primary objectives. One of the most important quantitative instruments in business decision-making. When trying to find the best way to do something, you must balance several competing priorities [66].

3.1.2 Process Optimization Tools

In order to arrive at the optimal answer, many steps are directly related to analytical methodologies. There is no truth to this. There is a requirement for statistical methods. But before committing to optimizing the process, a complete familiarity with the procedure is essential. One such method is Taguchi's D.O.E. [67].

3.1.3 Taguchi Design of Experiment:

The engineering design industry made extensive use of Taguchi's techniques. System design, parameter design, and tolerance design are all components of the Taguchi design of experiments, which aims to produce a reliable process and result for the best possible product quality. Perhaps Taguchi's parameter-based methods are the most reliable part of his methodology. In engineering terms, this is a method of creating a process or a product by zeroing in on the ideal values for the relevant variables. Maximizing output while minimizing variation in a performance indicator (quality measure). Taguchi designs offer a robust and effective method for developing processes that consistently and ideally function across various situations. A well-planned experiment that exposes the process across several design levels is required to identify the optimal design [68]. Methods for experimental design were developed at the turn of the twentieth century, and they have been the subject of extensive study by statisticians ever since. However, their complexity made them difficult for experts to employ. Taguchi's experimental design approach has widespread adoption in engineering and medicine because it can be easily implemented and used by people with minimum knowledge of statistics.

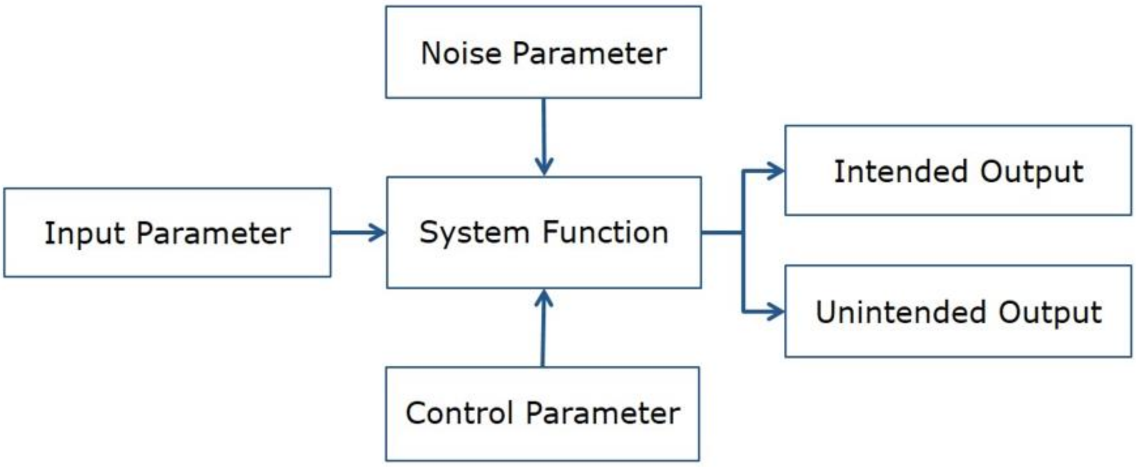

Figure 25: P-diagram

https://images.app.goo.gl/EGGeGve7tDoKA5Z46

Signal-to-noise (S/N) ratio has been Taguchi's primary metric of quality. The S/N ratio can be used as a metric in place of the standard deviation because, as it falls, the corresponding standard deviation reduces.[69], [70].

3.1.4 Taguchi's Rule for Manufacturing

Taguchi realized that the most effective means to eliminate variation are those built into a product and its manufacturing process. Therefore, he developed a method for quality engineering that can be applied in both settings. The procedure is broken down into three stages:

I. System design

II. Parameter design

III. Tolerance design

System design:

This is a conceptual design where originality and imagination play a crucial role.

Parameter design:

After the basic idea has been solidified, the detailed design phase of traditional engineering can begin by settling on standard values for the many dimensions and design factors. The term "robustification" can describe this phenomenon**.**

Tolerance design:

With a completed parameter design and an understanding of how changes to those parameters affect performance, efforts can be directed toward reducing the variables influencing the relatively few essential metrics [71].

3.1.5 Mathematical Modeling

Using O.A.s cuts down on the total number of possible experiments by a large margin. Montgomery (1991). Because of the wide variety of input parameters, Taguchi's orthogonal array design is typically used to dissect a process's performance characteristics[38]. As soon as the controllable parameters of a technique have been identified, it is imperative to ascertain the ranges of variation for each. Knowing a variable's minimum, maximum, and current value is essential in determining its testing range. If there is a big gap between a parameter's least and optimal value, the range of values examined can be expanded. A smaller array of a parameter means you may either test fewer values or space them out more closely. That way, fewer or more closely spaced values can be examined [72].

3.2 Experimental Setup

The "DK 7725" wire-cutting electric discharge machine was put through its paces in the lab. This WEDM utilizes a molybdenum electrode wire instead of brass, which is much more expensive. The cathode is made of molybdenum wire, and the anode is made of medium carbon steel. So that a spark may fly between the tool and the workpiece, a separation must be kept between the two. For this experiment, de-ionized water serves as the dielectric liquid. Fig.26 shows the molybdenum wire utilized in this experiment, and Table3 lists the molybdenum wire's technical parameters

Table 3: Molybdenum wire technical details

S/ No.	**Parameters**	**Unit**	**Value**
1	wire thickness diameter	mm	0.18
2	weight of wire rope	g	519
3	The overall length of the wire	M	2000

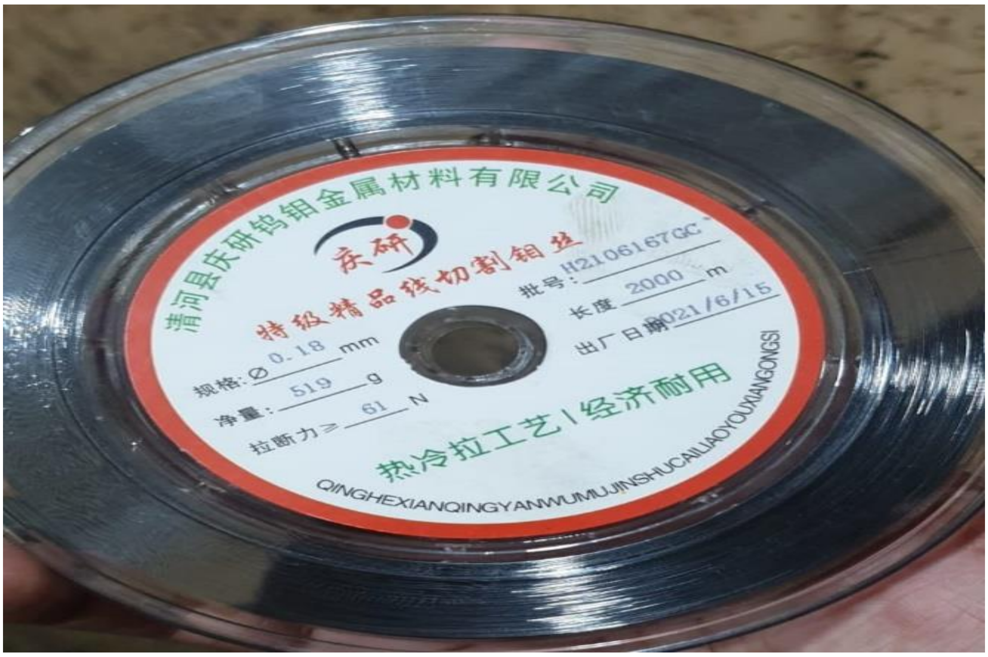

Figure 26: Molybdenum wire

The timing chain sprocket is a mechanical component made from AISI 1045 medium carbon steel. In this case, we went with an L9 orthogonal array. There were nine separate experiments conducted with varying levels of modifiable variables. Table 4 details the WEDM machine's technical spec, and fig.27 depicts the experimental setup used to conduct these evaluations. Table 5 provides the dimensions for the timing chain sprockets.

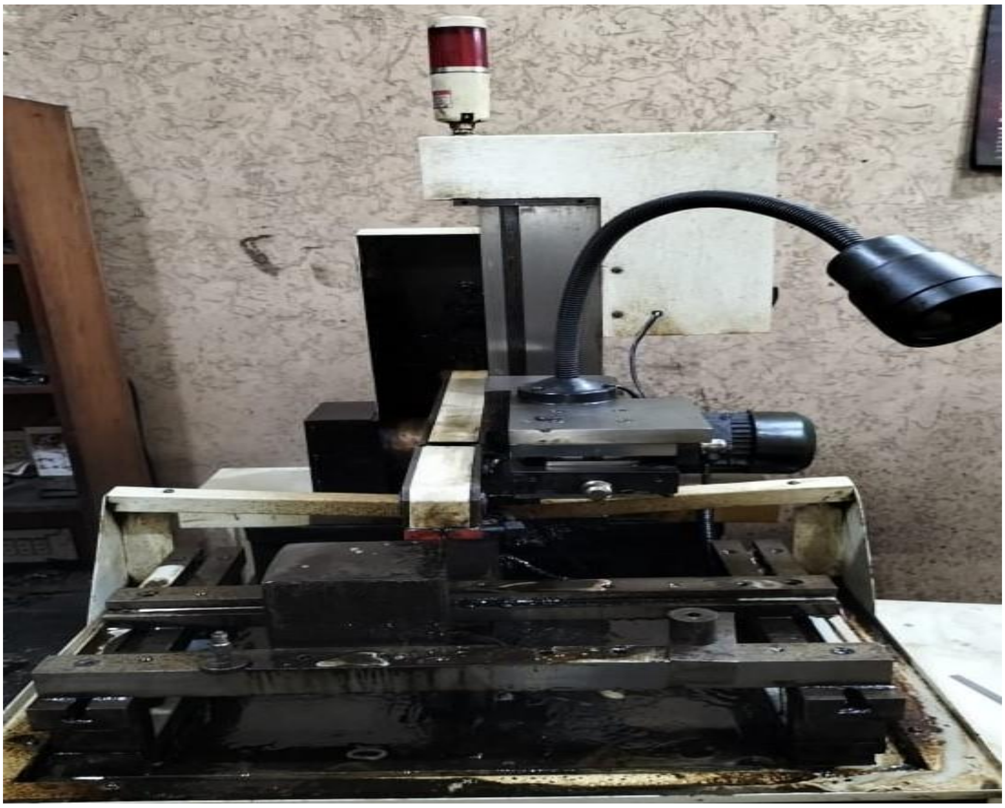

Figure 27: Wire cut electric discharge machine DK7725

Table 4: WEDM machine specifications

Specifications	Unit’s	DK7725
X-Y direction movement	mm	250×320
Table’s Size	mm	380×525
Max. cut thickness	mm	300 or 500
Cut taper/thickness	mm	±3* or ±30*/100
Cut accuracy	mm	≤0.015
Wireframe		Adjustable
Max. load of table	Kg	300
Weight of machine	Kg	1600
Dimension (L×W×H)	mm	1450×1100×1600

Table 5: WEDM machine specifications

S/ No	Parameters	Unit	Values
1	Outer diameter	mm	35.45
2	Height	m	30.8
3	Internal diameter	mm	24
4	Step diameter	mm	32
5	Step length	mm	6

3.2.1 Determination of process parameters and relevant settings

Following a thorough analysis of the available literature, the input control parameters presented in Table 6 have been determined as the most effective for use in this

Table 6: WEDM controllable process parameters

S/No	Control parameter	Unit
1	Current	Amp
2	Voltage	Volt
3	Pulse on Time	µs

The optimal settings for the control factors are then determined using the approach. We evaluate the levels of each process parameter in the WEDM machine in light of our process knowledge, given the importance of getting the right values for the controller settings while using D.O.E. The responsiveness of the output variable (such as the Material removal rate) to the factor The D.O.E. process parameter levels are shown in Table 7.

Table 7: Levels of process parameters for D.O.E.

Symbol	E.D.M. Machining Parameters	Unit	Level 1	Level 2	Level 3
I	Current	Amp	8	12	16
V	Voltage	Volt	50	55	60
Ton	Pulse on Time	µs	75	100	150

3.2.2 Selection of orthogonal array

Taguchi's orthogonal array is tailored to the control variables and parameters of interest. The number of elements, the relative importance of each factor, and the nature of their interactions all play a role in determining the optimal orthogonal array to use. Table 8 displays the ex's orthogonal array. The control elements are believed to be independent of one another. For this study, a Taguchi L9 Orthogonal array was used [40].

Table 8: L-9 Orthogonal array

Exp No	Pulse on Time	Current	Voltage
Exp-1	75	8	50
Exp-2	100	12	55
Exp-3	150	16	60
Exp-4	75	8	55
Exp-5	100	12	60

Timing chain sprockets in this experiment are made of AISI 1045 medium carbon steel. In this demonstration, molybdenum wire stands for steel, while de-ionized water acts as the dielectric. Nine separate experiments must be run with varying inputs. Wire electric discharge machining (WEDM) is extensively utilized in many industries because it can machine with high accuracy and produce a good quality surface finish while working with high-strength materials. WEDM is a cutting method that uses thermomechanical energy to remove materials. The electrode in this WEDM method is a moving molybdenum wire. The conductive work material is worn away during machining by applying heat energy and an electric spark. During the procedure, dielectric fluid is employed as an ionization medium to create electrical sparks between the work item and the cutting wire. A steady stream of dielectric fluid serves to wash away the tiny particles created by the electrical sparks and functions as a cooler.

3.2.3 Timing Chain Sprocket Design

Initially, the layout is created using CAD software and transferred into the WEDM device. The teeth profile of the timing chain sprocket gear was designed in CAD software and is seen in Fig.28. The timing chain gear teeth profile's various dimensions are emphasized. In Fig.29, we see the system sending commands to the WEDM machine's programmatic interface. This DK7725 wire-cut E.D.M. operates under the direction of the HF WEDM programme and control system. The basic component is fabricated first, and a gear cutting process is carried out. The illustration of this may be found in Fig. 31. Last but not least is a component known as a timing chain sprocket, which is depicted in Fig.32. With the aid of WEDM, the output quality of the work has increased dramatically.

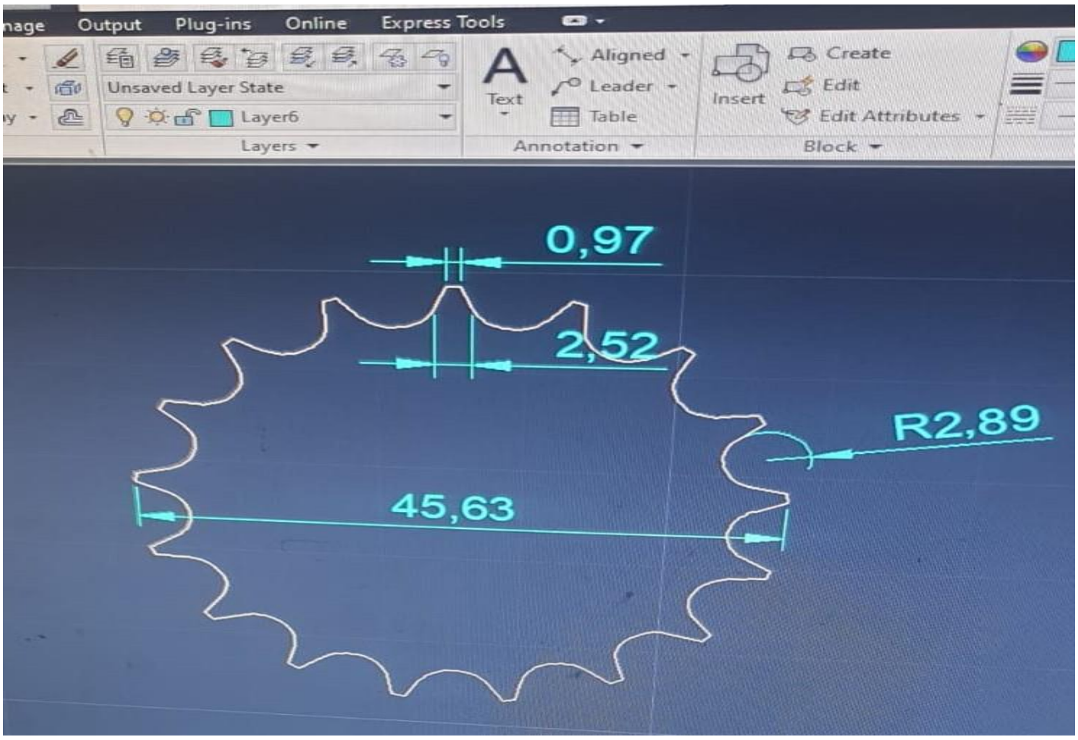

Figure 28: CAD design of timing chain sprocket

Figure 29: H.F. control system working on teeth's profile

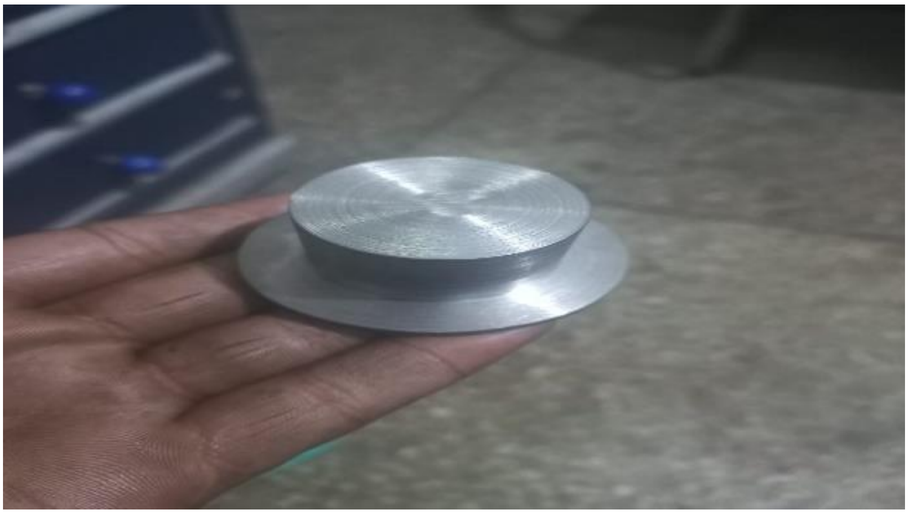

Figure 30: The base part of the timing chain sprocket

Figure 31: Gear cutting operation on AISI 1045 medium carbon steel

Figure 29: Final part

Table 9: Material removal rate for AISI 1045 medium carbon steel

Exp	**M.R.R.(mm3/min)**
E-1	0.211
E-2	0.3165
E-3	0.3798
E-4	0.221
E-5	0.411
E-6	0.7112
E-7	0.2421
E-8	0.3893
E-9	0.5123

3.2.4 Evaluation of M.R.R

Material Removal Rate is the percentage change in weight between a work piece's un-machined and machined state divided by the total amount of time spent machining the material and its density. [73].

$$M.R.R.(mm^3/min.) = \frac{[Initial\ Weight\ of\ workpiece(gm.) - Final\ Weight\ of\ Workpiece(gm.)]}{Density(gm./mm^3) \times Machining\ Time\ (min.)}$$

[73]

3.2.5 Calculation of Signal to Noise ratio and Analysis of Variance

Taguchi designs use resistance to lessen the impact of unpredictable variables in a product or process (noise elements). A system's control elements are the controllable aspects of its design and implementation. While manufacturing noise can only be managed by testing, it is nevertheless manageable. The purpose of a Taguchi-DOE is to find the optimal settings for your control elements to resist the effects of disturbances; hence keeping the noise variables under control is crucial. The higher the signal-to-noise ratio (s/n), the more the sensitive controls are aware of the need for such adjustments. Where "signal" denotes the desired value, and "noise" represents the undesired value, the signal-to-noise (S/N) ratio can be used to quantify the robustness of a design. Larger the better S/N ratio for MRR$\eta = -10\log_{10}[\frac{1}{MRR^2}]$[38].

In brief, ANOVA is a widely used statistical method for detecting variations in means. Using ANOVA, you may find out if there is statistically significant variation in the means of three or more groups. The p-value is crucial in ANOVA because it indicates the significance of responses and the degree to which error was introduced.

Table 10: Response table for the signal-to-noise ratio "Larger the better"

Pulse on Time	Current	Voltage	MRR	SNR
75	8	50	0.211	-13.5144
75	12	55	0.3165	-9.99253
75	16	60	0.3798	-8.4089
100	8	55	0.221	-13.1122
100	12	60	0.411	-7.72316
100	16	50	0.7112	-2.96017
150	8	60	0.2421	-12.3201
150	12	50	0.3893	-8.19431
150	16	55	0.5123	-5.80951

Table 11: Ranking of input parameters

Level	Pulse on Time	Current	Voltage
1	-10.639	-12.982	-8.223
2	-7.932	-8.637	-9.638
3	-8.775	-5.726	-9.484
Delta	2.707	7.256	1.415
Rank	2	1	3

Chapter 4: RESULTS & DISCUSSIONS

In this study, AISI 1045 medium carbon was subjected to nine separate trials, each with its own unique set of adjustable input variables. This experiment employed Taguchi D.O.E. to determine the optimal input factor settings for the L9 orthogonal array to remove as much material as possible. Table 10 displays the S/N ratio's findings; Table 11 ranks the outcomes. Based on Table 11's rankings, it's evident that current has the biggest impact on the rate at which material is extracted. Tables 12, 13, and 14 show the results of an analysis of variance. Check the p-values in these three tables. It will reveal which variable has the greatest effect on M.R.R. There is a stronger relationship between the input and response factors if the p-value for the input is less than.0.05, which is the threshold at which statistical significance is accepted. Current and M.R.R. are compared in Table 12. The p-value for current is 0.026, which is less than 0.05, indicating that current significantly affects the rate at which material is being removed.

Table 12: ANOVA for M.R.R. vs Current

Source	DF	Seq SS	Contribution	Adj S.S.	Adj MS	F-Value	P-Value
Current	2	0.14401	70.23%	0.14401	0.07200	7.08	0.026
Error	6	0.06105	29.77%	0.06105	0.01018		
Total	8	0.20506	100.0%				

Table 13: Model Summary for Table 12

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)
0.100873	70.23%	60.30%	0.137368	33.01%

Table 12's model summary shows that the R square percentage for current is equally high, at 70.2%, making it evident that current has a more significant impact. ANOVA results for M.R.R. MRR versus Voltage are shown in Table 13. Since the p-value for voltage is 0.780, which is more than.0.05, we may conclude that it does not play a role in the material removal rate in this experiment. Table 13's model summary reveals a similar finding; voltage has a negligible impact on M.R.R. as indicated by R-low sq's percentage of 7.93 percent.

Table 14 : ANOVA for M.R.R. vs Voltage

Source	DF	Seq SS	Contribution	Adj S.S.	Adj MS	F-Value	P-Value
Voltage	2	0.01627	7.93 %	0.01627	0.008133	0.26	0.780
Error	6	0.18880	92.07 %	0.18880	0.031466		
Total	8	0.20506	100.0 %				

Table 15: Model Summary for Table 14

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)
0.177386	7.93%	0.00%	0.424790	0.00%

The M.R.R. versus pulse on time ANOVA is displayed in Table 14. The results demonstrate that the pulse on time has a small effect on the material removal rate, with a p-value of 0.604, which is larger than 0.05, supporting the hypothesis. Based on the model summary, we know that R-sq is only 15.48%. Thus, we can deduce, using the 3 ANOVA tables, that rate of material removal is most affected by the current.

Table 16: ANOVA for M.R.R. vs Pulse on time

Source	DF	Seq SS	Contribution	Adj S.S.	Adj MS	F-Value	P-Value
Pulse on Time	2	0.03174	15.48 %	0.03174	0.01587	0.55	0.604
Error	6	0.17322	84.52 %	0.17332	0.02889		
Total	8	0.20506	100.0 %				

Table 17: Model Summary for Table 16

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)
0.169959	15.48%	0.00%	0.389964	0.00%

According to fig.33, and 34 the material removal rate increased with both current and voltage. It reveals a small rise in material removal rate with higher voltage but a drop with a longer pulse. Thus, I = 16-amp, V = 50-volt, and pulse on time = 100s are the optimal input parameters for this investigation. We can maximize material removal and accelerate timing chain sprocket manufacture using these settings.

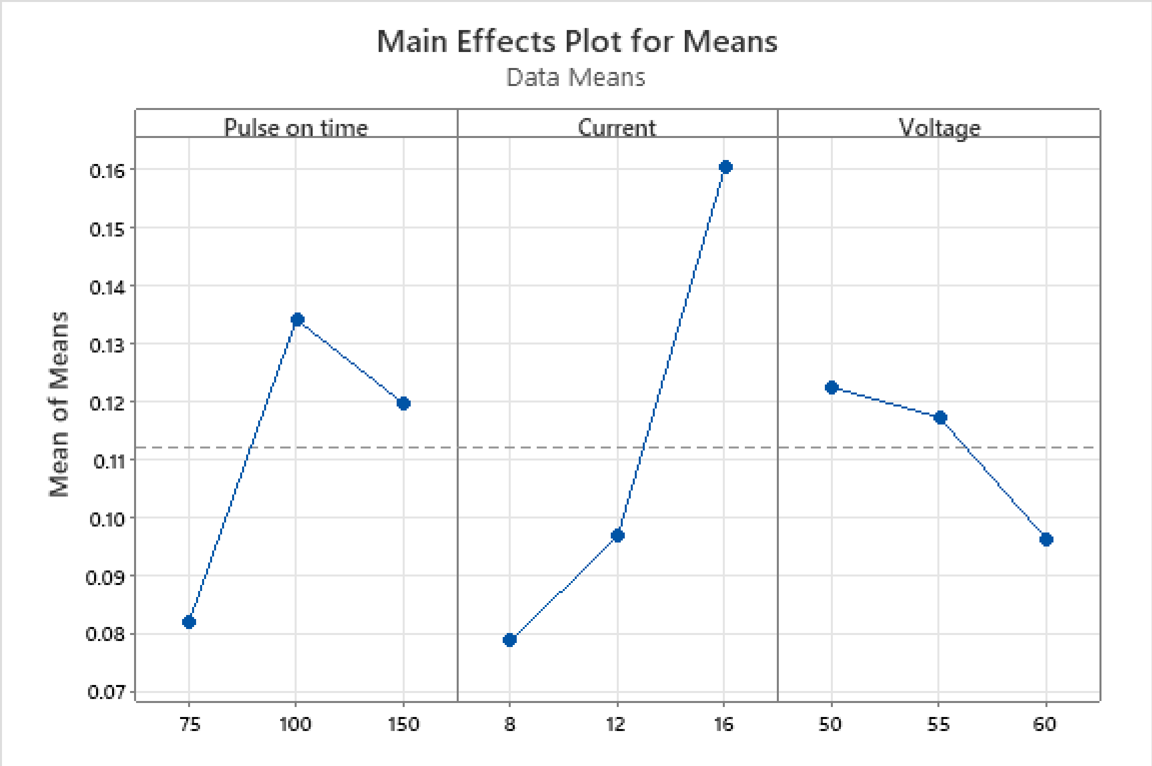

Figure 33: Main effect plot for means

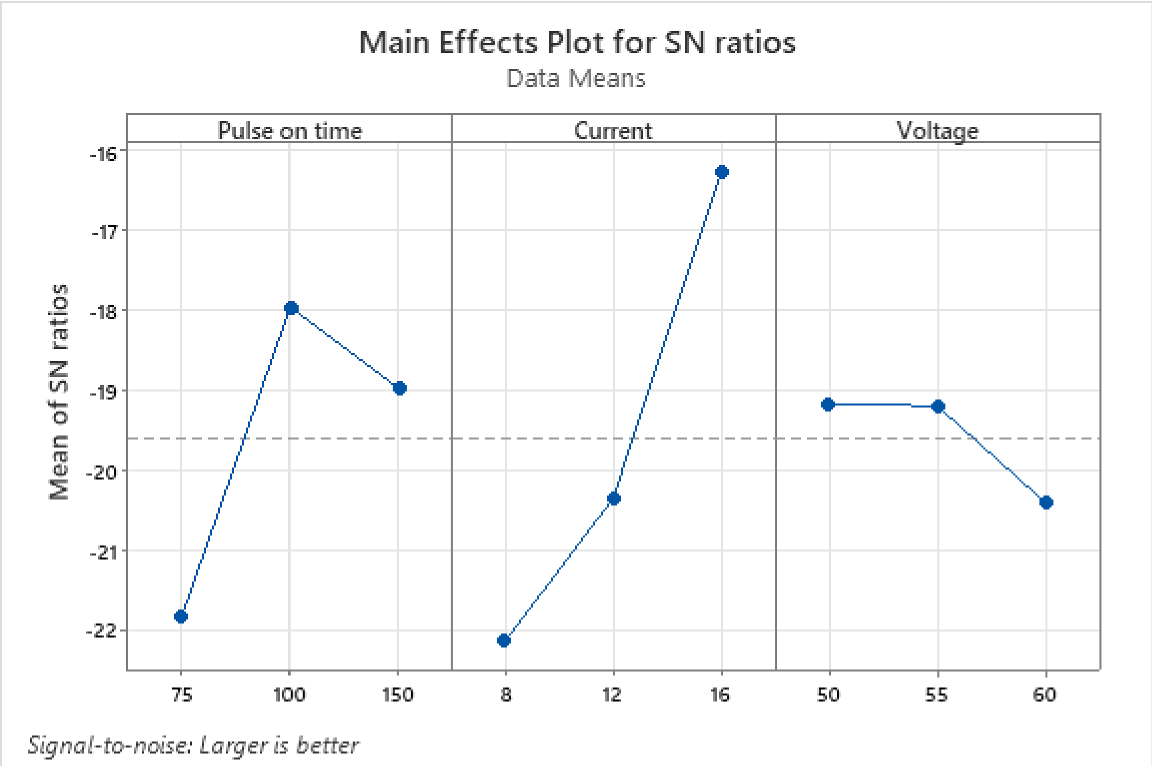

Figure 304: Main effects plot for SN ratio

Chapter 5: Conclusions and Future work

Our goal in doing this research was to better understand the connection between the material removal rate and the WEDM process input parameters for a specific automotive, industrial case. The L9 orthogonal array designed by Taguchi was utilized to optimize the manufacturing process for AISI 1045 medium carbon steel. Through analysis of variance, we may ascertain which machining elements are most consequential in influencing M.R.R. The following are the findings from the investigation: For AISI 1045 medium carbon steel, current is the most influential input parameter. Accelerated deposition occurs when the current is increased. The material removal rate reduces with increasing voltage. Also, the material removal rate drops with an increasing pulse on time. Table 11 displays that For M.R.R., the most influential factor is current, as it is ranked first. The graph shows that the ideal parameters for increasing the material removal rate are I = 16-amp, V = 50-volt, and pulse on time = 100-s. In this study, we use a method that allows for simple re-design of the components if the provided process parameters do not meet the functional requirements. Utilizing a multi-objective optimization technique, further study can be conducted. This study provides the scope for future studies to widen the number of WEDM parameters to be used, such as wire tension, pulse off time, and wire speed; the following are a few recommendations for potential directions for future research.

- Levels of input parameters can be increased; such as four or five levels of input parameter values can be used to reduce the possibility of data loss during statistical analysis.
- More WEDM parameters can be used, such as wire tension, wire speed, pulse off time, etc., to understand their effect on M.R.R.
- More than one output parameter can be used in the future to find surface roughness, tool wear rate, etc.
- Different Grade of steel can be used to make Timing chain sprocket gear with different input and output parameters.
- Combined F.E.A. and Taguchi method can be used for future studies to achieve better results for mechanical strength.

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