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Optimization of Plasma Arc Cutting process, Using Taguchi Method

Submitted in Partial Fulfillment for the Award of the Degree of

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Submitted By
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(FORMERLY DELHI COLLEGE OF ENGINEERING)
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CERTIFICATE

I hereby declare that the work which is being presented in the thesis entitled ***“*****Optimization of Plasma Arc Cutting process,Using Taguchi Method*****”*** in partial fulfillment for the award of degree of **Master of Technology** with specialization in **“Production Engineering”** submitted to **Delhi Technological University**, is authentic record of my own work carried out under the supervision of **Mr. Rajiv Chaudhary,** Department of Mechanical Engineering, Delhi Technological University. I have not submitted the matter in this dissertation for the award of any other Degree or Diploma or any other purpose whatever.

Date: July 02,2012

Sumit Chaudhary

14/PRD/2K10

This is to certify that above statement made by the candidate is true to the best of my knowledge and belief.

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ABSTRACT

Plasma arc cutting (PAC) is a widely used industrial process for the cutting of different types of metals in several operating conditions. PAC is considered a challenging technology compared to its main competitors: oxy-fuel and laser cutting, in particular for cutting of mild steel in the thickness range 8-40 mm. PAC of mild steel thin plates through a KALI-100 Plasma Arc Cutting Machine, operating in the range 25-120 A. PAC of mild steel thin plates (thickness in the range 5-15 mm) are characterized by low current levels (65-135 A) and the use of air both as plasma gas and secondary gas. The aim of the work is the optimization of PAC of mild steel thin plates, both in terms of cut quality and performances of the consumables, to achieve cut quality standards and productivity levels usually obtainable through laser cutting processes. The first part of the work points out the main critical aspects of the considered cutting process, concerning both the obtained qualitative standards and the performances of the consumables, in particular of the nozzle, in terms of its service life. In the second part of the work, the optimization the process has been carried out by using Taguchi Method and analysis of experimental tests and numerical simulations. Experimental tests have allowed a better design of consumables, in particular nozzle stand-off distance, pressure of air which is delivered by the compressor, and to optimize current profiles and torch travelling speed by using Taguchi Method a the statistical tool for measuring the optimum level of the process. The output parameters are kerf and Heat Affected Zone, both are undesirable so had to be minimize. Taguchi L9 orthogonal array is used having for parameters having three levels. Taguchi Method have allowed a better

understanding of the physical phenomena concerning the critical aspects initially pointed out and to detect successful optimum design solutions. The integration of the results of these two activities has allowed overcoming the critical aspects initially pointed out, improving plasma jet constriction and reducing plasma jet instabilities, leading to a better cut quality and performances of the consumables.

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Abbreviations

PAC = Plasma Arc Cutting

PAW = Plasma Arc Welding

S/N ratio = Signal-to-noise ratio

DOE = Design of Experiment

WEDM = Wire Electrical Discharge Machining

MRR = Metal Removal Rate

SF = Surface Finish

CNC = Computer Numerical Control

dB = decibels

OA = orthogonal array

Psi = per Square Inch

ANOVA = Analysis of Variance

HAZ = Heat Affected Zone

KAV = Kerf Average Value

KS/NR = Kerf S/N Ratio

HAZAV = Heat Affected Zone Average Value

HAZS/NR = Heat Affected Zone S/N Ratio

INTRODUCTION

CHAPTER 1

Plasma cutting technology is one in which argon, nitrogen and compressed air are used to generate a plasma jet and then nonferrous metal, stainless steel and black metal are cut by the high temperature of the highly-compressed plasma arc and the mechanical erosion of the fast plasma jet. This technology has grown since its introduction in the 1950s to compete with flame cutting process for thick plates (upto 60 mm) and laser cutting technology for thin plates (upto1 mm). It has recently been used widely for processes of blanking, rough machining and structure components stocking in shipbuilding industry, machine manufacturing industry, etc. However, it is hard to establish a special mathematical model to accurately describe the cutting characteristics, because the power supply has nonlinearity and its cutting parameters have dynamic coupling and static superposition in the cutting process. The conventional control strategy cannot satisfy the control requirements of the modern cutting process for an inverted power supply. In spite of its development, the field was given little attention by the Researchers. The different processes included in the plasma cutting process are plasma material Interaction, process control, thermal plasma generation, liquid metal removal, Etc. In the process of plasma cutting, a transferred electric arc is established between the Negative electrode and the work piece within the cutting torch. The arc that is generated has to be narrow so that the power density is enough and the heat diffusion takes place Very rapidly across the metal plate thickness. For cutting with plasma an adequate amount of power and force should be transferred to the work piece. Then, the work piece melts and the metal that is melted is removed from the cut. By definition, plasma means a low-ionized gas, in which the individual atoms get ionized. In other words, plasma is a gas that is heated to a higher temperature and is ionized so as to become electrically conductive (Farnum, 2006). According to the Thermal Dynamics Torch Manual (2007), in the processes of plasma, the plasma gas transfers an electrical arc to the work piece. The heat of the arc melts the metal that has to be cut and removed. Another process of plasma is plasma gouging. This process removes metal to a controlled depth and width. Among several plasma applications, the cutting Application is superior. The major difference between PAC and plasma arc welding (PAW) is the Velocity of the orifice gas. (In some cases, a shielding gas as well as a cutting Or orifice gas may be used. The shielding gas prevents oxidation of the cut surface.), the higher velocity gas used I PAC removes or blows away the molten material. The PAC process can be used to cut any electrically conductive metal if its Thickness and shape permit full penetration by the plasma jet. Because the PAC Process can be used to cut nonferrous materials and is faster than oxy fuel cutting Cutting in ferrous materials 2 inches thick or less, it is suitable for many industrial Applications. Since PAC was introduced in 1954, many process refinements, gas developments, and equipment improvements have occurred.

The Taguchi method, a systematic application in design and analysis of experiments, is used for

Designing and improving product quality. It has become a powerful tool for improving productivity during research and development so that high quality products can be produced and costs reduced. However, the original Taguchi method was designed to optimize a single performance characteristic. Furthermore, optimization of performance characteristics is much more complicated than optimization of a single performance characteristic. Dr. Genichi Taguchi is regarded as the foremost proponent of robust parameter design, which is an engineering method for product design that focuses on minimizing variation and or sensitivity to noise. When used properly, Taguchi design provides a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. In robust parameter design the primary goal is to find factor settings that minimize response variation, while adjusting (or keeping) the process on target. After you determine which factors affect variation, you can try to fine settings for controllable factors that will either reduce the variation, make the product insensitive to changes in uncontrollable (noise) factors, or both, a process designed with this goal will produce more consistent output. a product designed with this goal will deliver more consistent performance regardless of the environment in which it is used. Engineering knowledge should guide the selection of factors and responses [3]. Robust parameter design is particularly suited for energy transfer processes; for example, a car’s steering wheel is designed to transfer energy from the steering wheel to the wheels of the car. You should also scale control factors ad responses so that interactions are unlikely. When interactions among control factors are likely or not well understood, you should choose a design that is capable of estimating those interactions. Minitab can help you select a Taguchi design that does not confound interactions of interest with each other or may require preliminary experimentation. The noise levels selected should reflect the parameter design uses Taguchi designs (orthogonal arrays), which allow you to analyze many factors with few runs. Taguchi designs are balanced, that is no factor is weighted more or less in an experiment, thus allowing factors to be analyzed independently of each other. Minitab provides both static and dynamic response experiments.

- In a static response experiment, the quality characteristic of interest has a fixed level.
- In a dynamic response experiment, the quality characteristic operates over a range of values and the goal is to improve the relationship between an input signal and an output response. An example of a dynamic response experiment is an automotive acceleration experiment where the input signal is the amount of pressure on the gas pedal and the output response is vehicle speed. You can create a dynamic response experiment where the input signal is the amount of pressure on the gas pedal and the output response is vehicle speed. You can create a dynamic response experiment by adding a signal factor to a design- see creating a dynamic response experiment by of robust experimentation is to find an optimal combination of control factor settings that achieve robustness. Against (insensitivity to) noise factors, Minitab calculates response tables, linear model results, and generates main effects and interaction plots for:
- Signal-to-noise radios (S/N rations, which provide a measure of robustness) vs. the Control factors.
- Means (static design) or slopes (dynamic design vs. the control factors
- Standard deviations vs. the control factors.
- Natural log of the standard deviations vs. the control factors.

Use the results and plots to determine what factors and interactions are important and evaluate how they affect responses. To get a complete understanding of factor effects it is advisable to evaluate S/N ratios, means (static design), slopes (dynamic design), and standard deviations, Make sure that you choose an S/N ratio that is appropriate for the type of data you have and your goal for optimizing the response.

1.1 Plasma Arc Cutting

Plasma arc cutting was developed 20 years ago primarily for cutting stainless steel and aluminum. Although favorable economically, mild steel was seldom cut with this process because of three fundamental limitations: relatively poor cut quality, equipment reliability, and inability of the earlier cutting machines to handle plasma cutting speeds. As a result of these limitations, plasma cutting did not encounter rapid growth until after Water-injection Plasma Cutting was introduced in 1970.

This relatively new process differs from conventional, "dry" plasma cutting in that water is injected around the arc. The net result is greatly improved cut quality on virtually all metals, including mild steel. Today, because of advances in equipment design and improvement in cut quality, previously unheard of applications, such as multiple torch cutting of mild steel, are becoming commonplace.

This paper reviews the concept of the water constricted arc. First the fundamentals and the limitations of the conventional plasma cutting process are reviewed. Then the technique of Water-injection is described and typical cutting speeds are presented. Finally, the process capabilities in terms of improved cut quality and equipment capability are specified.

1.2 Arc Constriction

In the early 1950's, it was discovered that the properties of the open arc, ie, Tig welding arc, could be greatly altered by directing the arc through a water-cooled copper nozzle located between an electrode (cathode) and the work (anode). Instead of diverging into an open arc, the nozzle constricts the arc into a small cross section. This action greatly increases the resistive heating of the arc so that both the arc temperature and the voltage are raised. After passing through the nozzle, the arc exits in the form of a high velocity, well collimated and intensely hot plasma jet as shown below.

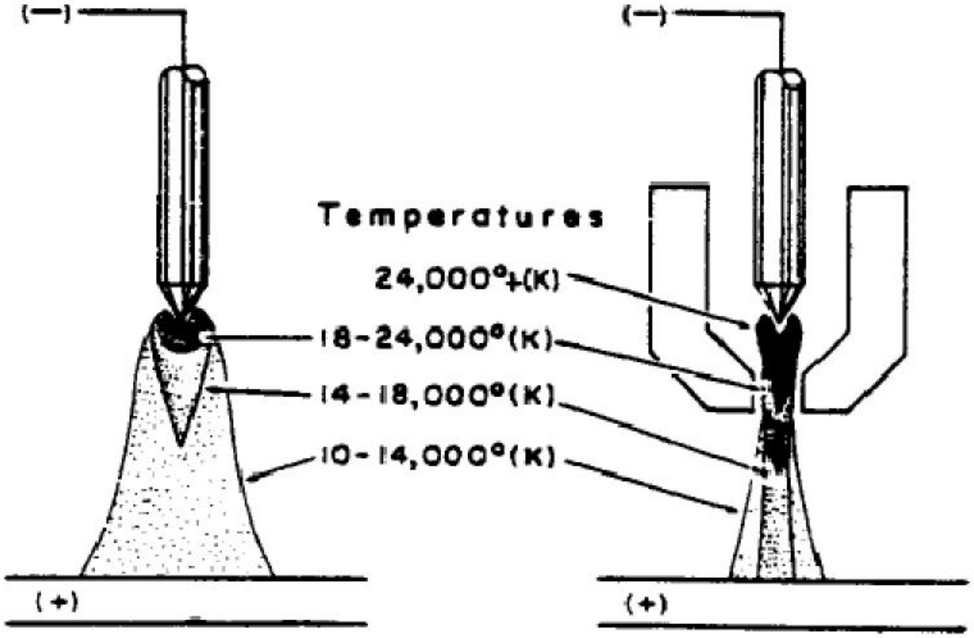


Fig 1.1 Temperature Differences

In this example, both discharges are operating in argon at 200 amps. The plasma jet is only moderately constricted by the 3/16-inch diameter nozzle, but operates at twice the voltage and produces a much hotter plasma than the corresponding open arc.

A plasma jet can either be operated in the transferred mode, where the power supply is connected between the electrode and the workpiece, or in the non transferred mode where the power supply is connected between the electrode and the nozzle. Both modes of operation are illustrated in Figure 2. Although a stream of hot plasma emerges from the nozzle in both modes of operation, the transferred mode is always used in plasma cutting because the usable heat input is most efficiently applied when the arc is in electrical contact with the workpiece.

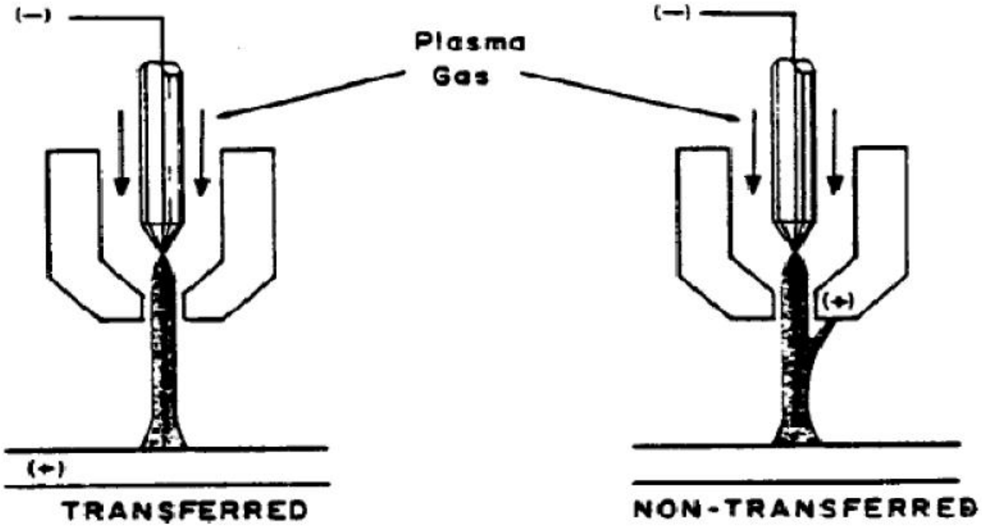


Fig. 1.2 - Two Basic Types of Constricted Arcs

The characteristics of the plasma jet can be altered greatly by changing the gas type, gas flow rate, arc current, and nozzle size. For example, if low gas flow rates are used, the plasma jet will be a highly concentrated heat source ideal for welding. Conversely, if the gas flow rate is increased sufficiently the plasma jet will cut through the workpiece; the velocity of the plasma jet will be high enough to blast away the molten metal created by the plasma arc. In this paper only the plasma cutting process--the use of a plasma arc developed under conditions of high gas flow and high current--will be discussed. The plasma cutting arc is considerably hotter than the example described above in Figure 1.1. Greater temperatures are possible because the high gas flow forms a realtively cool boundary layer of unionized gas inside the nozzle bore, thereby allowing a higher degree of arc constriction. The thickness of this boundary layer can be further increased by swirling the cutting gas: The swirling action forces the cool, unionized gas to move radially outward and form a thicker boundary layer. Most mechanized plasma cutting torches swirl the cutting gas to attain maximum arc constriction.

1.3 Types of Plasma Arc Cutting:

1.3.1 Conventional Plasma Arc Cutting

The plasma arc cutting process is illustrated in Fig. 1.3. The basic principle is that the arc formed between the electrode and the workpiece is constricted by a fine bore, copper nozzle. This increases the temperature and velocity of the plasma emanating from the nozzle. The temperature of the plasma is in excess of 20 000°C and the velocity can approach the speed of sound. When used for cutting, the plasma gas flow is increased so that the deeply penetrating plasma jet cuts through the material and molten material is removed in the efflux plasma.

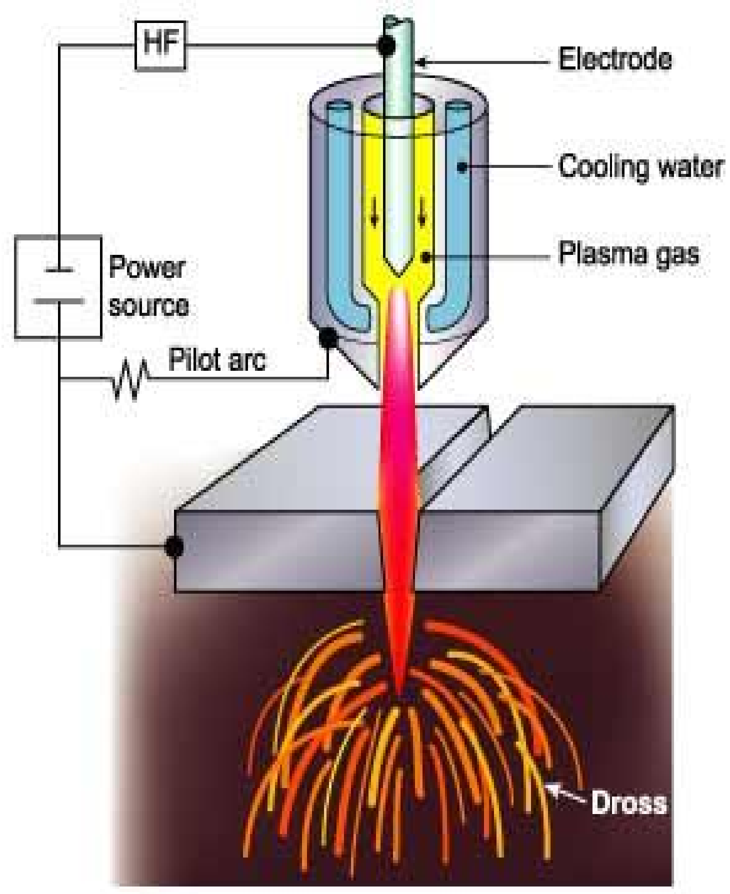


Fig.1.3. The plasma arc cutting process

The process differs from the oxy-fuel process in that the plasma process operates by using the arc to melt the metal whereas in the oxy-fuel process, the oxygen oxidises the metal and the heat from the exothermic reaction melts the metal. Thus, unlike the oxy-fuel process, the plasma process can be applied to cutting metals which form refractory oxides such as stainless steel, aluminum, cast iron and non-ferrous alloys.

1.3.1.1 Power Source

The power source required for the plasma arc process must have a drooping characteristic and a high voltage. Although the operating voltage to sustain the plasma is typically 50 to 60V, the open circuit voltage needed to initiate the arc can be up to 400V DC.

On initiation, the pilot arc is formed within the body of the torch between the electrode and the nozzle. For cutting, the arc must be transferred to the workpiece in the so-called ’transferred’ arc mode. The electrode has a negative polarity and the workpiece a positive polarity so that the majority of the arc energy (approximately two thirds) is used for cutting.

1.3.1.2 Gas Composition

In the conventional system using a tungsten electrode, the plasma is inert, formed using either argon, argon-H_2 or nitrogen. However, as described in Process variants, oxidizing gases, such as air or oxygen, can be used but the electrode must be copper with hafnium.

The plasma gas flow is critical and must be set according to the current level and the nozzle bore diameter. If the gas flow is too low for the current level, or the current level too high for the nozzle bore diameter, the arc will break down forming two arcs in series, electrode to nozzle and nozzle to workpiece. The effect of ’double arcing’ is usually catastrophic with the nozzle melting.

1.3.1.3 Cut Quality

The quality of the plasma cut edge is similar to that achieved with the oxy-fuel process. However, as the plasma process cuts by melting, a characteristic feature is the greater degree of melting towards the top of the metal resulting in top edge rounding, poor edge squareness or a bevel on the cut edge. As these limitations are associated with the degree of constriction of the arc, several torch designs are available to improve arc constriction to produce more uniform heating at the top and bottom of the cut.

1.3.2 Dual Gas

The process operates basically in the same manner as the conventional system but a secondary gas shield is introduced around the nozzle, Fig.1.4. The beneficial effects of the secondary gas are increased arc constriction and more effective ’blowing away’ of the dross. The plasma forming gas is normally argon, argon-H2 or nitrogen and the secondary gas is selected according to the metal being cut.

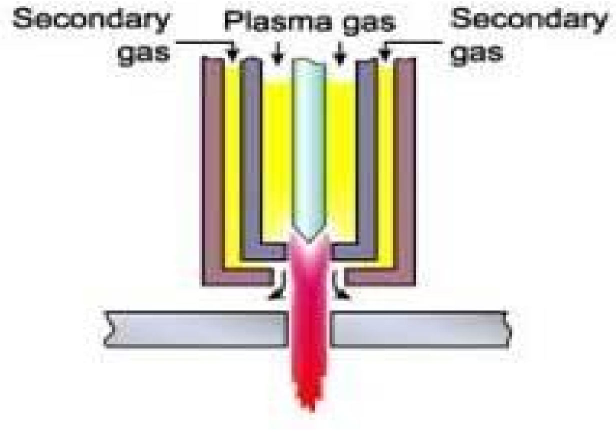


Fig.1.4. Dual Gas PAC

Steel

air, oxygen, nitrogen

Stainless steel

nitrogen, argon-H_2, CO_2

Aluminium

argon-H2, nitrogen / CO_2

The advantages compared with conventional plasma are:

- Reduced risk of ’double arcing’
- Higher cutting speeds
- Reduction in top edge rounding

1.3.3 Water Injection

Nitrogen is normally used as the plasma gas. Water is injected radially into the plasma arc, Fig.1.5, to induce a greater degree of constriction. The temperature is also considerably increased, to as high as 30,000°C. The water which is injected can be used for producing plasma gas, or can be used as coolant to improve the quality of cutting as compared to the first two cases. Moreover the temperature developed in this case is much higher.

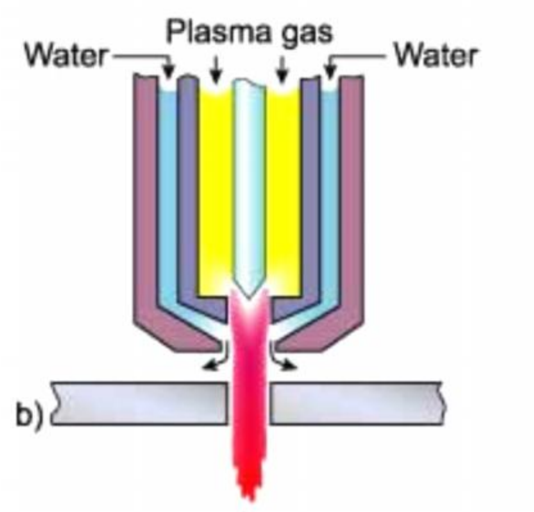


Fig.1.5. water injection

The advantages compared with conventional plasma are:

- Improvement in cut quality and squareness of cut
- Increased cutting speeds
- Less risk of ’double arcing’
- Reduction in nozzle erosion

1.3.4 Water Shroud

The plasma can be operated either with a water shroud, Fig.1.6, or even with the workpiece submerged some 50 to 75mm below the surface of the water. Compared with conventional plasma, the water acts as a barrier to provide the following advantages:

- Fume reduction
- Reduction in noise levels
- Improved nozzle life

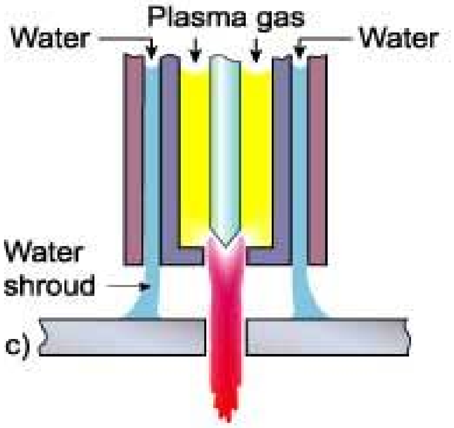


Fig.1.6. Water shroud

In a typical example of noise levels at high current levels of 115dB for conventional plasma, a water shroud was effective in reducing the noise level to about 96dB and cutting under water down to 52 to 85dB. improved. As the water shroud does not increase the degree of constriction, squareness of the cut edge and the cutting speed are not noticeably.

1.3.5 Air Plasma

The inert or nonreactive plasma forming gas (argon or nitrogen) can be replaced with air but this requires a special electrode of hafnium or zirconium mounted in a copper holder, Fig.1.7. The air can also replace water for cooling the torch. The advantage of an air plasma torch is that it uses air instead of expensive gases.

It should be noted that although the electrode and nozzle are the only consumables, hafnium tipped electrodes can be expensive compared with tungsten electrodes.

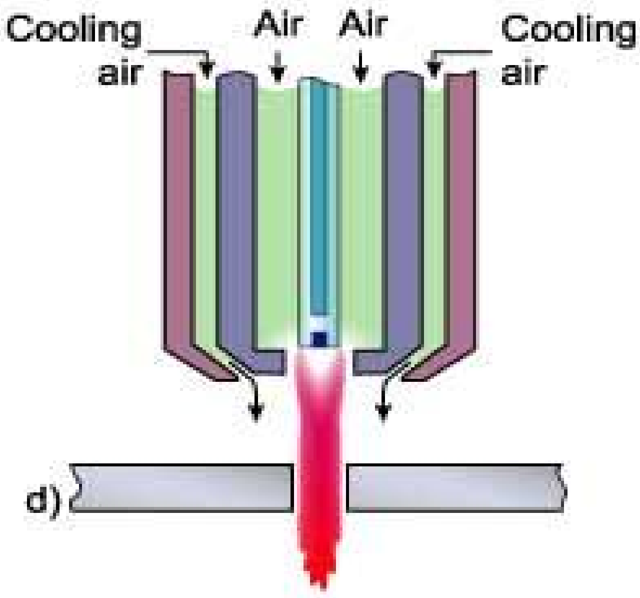


Fig.1.7. Air PAC

1.3.6 High Tolerance Plasma

In an attempt to improve cut quality and to compete with the superior cut quality of laser systems, High Tolerance Plasma Arc cutting (HTPAC) systems are available which operate with a highly constricted plasma. Focusing of the plasma is effected by forcing the oxygen generated plasma to swirl as it enters the plasma orifice and a secondary flow of gas is injected downstream of the plasma nozzle, Fig.1.8. Some systems have a separate magnetic field surrounding the arc. This stabilizes the plasma jet by maintaining the rotation induced by the swirling gas. The advantages of HTPAC systems are:

- Cut quality lies between a conventional plasma arc cut and laser beam cut
- Narrow kerf width
- Less distortion due to smaller heat affected zone

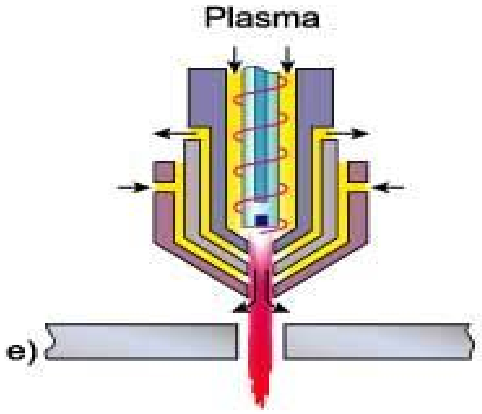


Fig.1.8. High Tolerance PAC

HTPAC is a mechanized technique requiring precision, high-speed equipment. The main disadvantages are that the maximum thickness is limited to about 6mm and the cutting speed is generally lower than conventional plasma processes and approximately 60 to 80% the speed of laser cutting.

1.4. APPLICATIONS

The machining technologies based on the thermal effect of plasma have an important place in the field of unconventional technologies at present the plasma arc machining represent one of the most modern machining technologies used in the industry domains such as :machines manufacturing, electronics ,aeronautics, etc. due to its advantages ,to the fact that it allows machining of the high alloy refractory and stainless steel with maximum productivity, to the automation capacity ,to the low expenses towards traditional techniques, and also due to the quality obtained of the surface material.

Plasma cutting is used to cut particularly those nonferrous and stainless metals that cannot be cut by the usual rapid oxidation induced by ordinary flame torches. Plasma cutting can be used for stack cutting, plate beveling, and shape cutting and piercing. With some modifications, plasma arc cutting can be used under water.) Plasma arc cutting finds applications in many industries such as shipyard, chemical, nuclear and pressure vessel. It is used for removing gates and risers in foundry. It cuts hot extrusions to desired length. It is used to cut any desired pipe contour. It is also employed for gouging applications. It finds use in the manufacture of automotive and railroad components.

It cuts carbon steel up to 10 times faster than oxy-fuel cutting, with equal quality more economically It leaves a narrower kerf Plasma cutting being primarily a melting process can cut any metal. Arc plasma torches give the highest temperature available from many practicable sources. The energy seems to be unlimited in this method.

1.5 Other Plasma Arc Processes

Depending upon the design of the torch (e.g., orifice diameter), electrode design, gas type and velocities, and the current levels, several variations of the plasma process are achievable, including:

1) Plasma arc cutting 2) Plasma arc gouging 3) Plasma arc surfacing

1.6 Objective of Work

This research is carried out on KALI-100 Model of Plasma Arc Cutter. We can have four variables in this models which are current, torch travelling speed, Torch Stand-off distance, supply air pressure. The output parameters are kerf and Heat Affected Zone which are to be minimize to have optimize settings of process parameters.

The statistical tool used in the research is Taguchi Method. Taguchi L9 orthogonal array is used for the calculation of optimum process parameters. The percentage effect of each process variable is also studied.

Taguchi parameter design to optimize the roundness of holes made by an aging plasma-cutting machine. An L9 array is used in a Taguchi experiment design consisting of four controllable factors, each with three levels. With two non-controllable factors included in the setting, we conduct 36 experiments, compared to the 81 parameter combinations (four factors, three levels or 34) required in a traditional DOE setting. Therefore, using the Taguchi method significantly reduces the time and costs of a quality improvement process. Conducted for two response variables—bevel magnitude and the smallest diameter deviation of the hole—the Taguchi experiments gave the optimal combination A1B2C1D3 (small for tip size, 93 in/min for feed rate, 100 V for voltage, and 63A for amperage.[1]

Optimized the parameters of plasma arc welding (PAW) by the Taguchi method with Grey relational analysis is studied. The Grey relational grade is used to find optimal PAW parameters with multiple response performance characteristics. The welding parameters (welding current, Welding speed, plasma gas flow rate, and torch stand-off) are optimized with consideration of the multiple response performance characteristics (the penetration of root, the weld groove width, and the weld pool undercut). As a result, the improvement percentage of the Grey relational grade with the multiple performance characteristics is 31.8%. It is shown that the multiple response performance characteristics are greatly improved through this study.[2]

Studied Wire electrical discharge machining (WEDM) is extensively used in machining of conductive materials when precision is of prime importance. Rough cutting operation in WEDM is treated as a challenging one because improvement of more than one machining performance measures viz. metal removal rate (MRR), surface finish (SF) and cutting width (kerf) are sought to obtain a precision work. Using Taguchi's parameter design, significant machining parameters affecting the performance measures are identified as discharge current, pulse duration, pulse frequency, wire speed, wire tension, and dielectric flow. It has been observed that a combination of factors for optimization of each performance measure is different. [3]
An optimization of the cutting parameters during CNC plasma-arc cutting of St37 mild steel plates is attempted using robust design. The process parameters tested were plate thickness, cutting speed, arc ampere, arc voltage, air pressure, pierce height, and torch standoff distance. An orthogonal matrix experiment [L18 (21 × 37)] was conducted and the right bevel angle was measured and optimized according to the process parameters using an analysis of means and an analysis of variances.[4]

There is available a design method for a product which is robust and can fulfill its function without failure under any service conditions and environmental conditions. This method is called a robust method or Taguchi's Methods in the U.S.A. and is called quality engineering in Japan. Taguchi's Methods have received much attention in the U.S.A. since the 1980s as an engineering development method developed in Japan, and were imported back into Japan in the 1990s. Many successful results obtained by the application of the Methods such as q elimination of various quality nonconformities, w reduction in failure and cost by half, e dramatic improvement in machining accuracy and production efficiency, and r reduction in development lead time by half have been reported successively. [5]

The paper proposes a hybrid approach, integrating a combination of Taguchi methods, principal component analysis (PCA) and fuzzy theory for the extended optimization of multiple quality characteristics in optimization experiments of non-image optics; a miniature light emitting diode pocket-sized projection display system is demonstrated in this research as an optimization sample. Traditionally, the performance of projector optics can be evaluated by modulation transfer function and its optimization method is DLS (damped least square). Comparatively, light efficiency and uniformity play a part in non-image optics where the optimized method is based on the concept of non-sequential rays; for example, in the optical engine of a projector, which demands better light efficiency and uniformity. The DLS method is occasionally employed in the optimization of non-image optics such as optical engines, but it is sometimes sensitive to the number of rays employed and some over-optimization problems. In this research we propose as an alternative method to optimize in an extended way the optical engine of a miniature projector. Control factors were checked and then repeatedly examined before the experiments started. In the experiment, optimization works through an L18 orthogonal array. Finally, this proposed optimization work shows good success for the optimization of non-image optical engines because this method is less sensitive to the number of non-sequential rays. Compared with the initial design, the optimized parameter design is able to improve the luminous flux by 11.46 dB, the illumination uniformity by 3.14 and the packing size by 1.125 dB.[6]

The thick photo resist SU8, by virtue of its good mechanical durability, water impermeability and dielectric properties on polymerization, is widely used as a resin for making high aspect ratio, functional MEMS device structures and packaging parts. However, the difficulty associated with removal, stripping or re-patterning of the polymerized SU8 remains a serious issue. This paper presents a novel process, based on O2/SF6 plasma etching, for patterning or removal of fully cross-linked SU8. The Taguchi methodology is used to optimize the O2/SF6 mix for a high etch rate and low under cut.[7]

Reported the results of a study on the influence of oxygen in the plasma gas used in the plasma arc cutting process on cuts obtained in mild steel plates. Experimental results of shapes of kerfs and the leading edges of the cut front formed while cutting a 6 mm mild steel plate at 100 A with nitrogen, air and oxygen as plasma gases are presented. These results are discussed in the light of the overall energy balance of the process. It is found that the exothermic reaction of oxygen in the plasma gas with the iron in mild steel enables the cutting of mild steel at higher speeds with both air and oxygen than the maximum cutting speed attainable with nitrogen. A comparison of the melting rates for oxygen with those of air reveals that although oxygen can produce more exothermal energy by oxidation, oxygen is not superior to air in melting metal near the bottom of the kerf formed at high cutting speeds. [8]

In this study, AISI 304 stainless steel and St 52 carbon steel have been cut by plasma arc and the variations of structural specifications occurred after cutting has been investigated. According to the experimental results, it has been seen that burning of particulars and distribution amount were increased when the cutting was performed using the speeds which are upper or lower limits of the ideal cutting speeds proposed by the manufacturer of the machine tool. Moreover, it was determined that the hardness from the outer surface to the core decreased, while the hardness near to the outer surface which affected by the high temperature occurred during cutting increased.[9]

To reduce the kerf width and to improve the kerf quality, the hydro-magnetically confined plasma arc was used to cut engineering ceramic plates. By experiments and analyses, the characteristics of the hydro-magnetic confined plasma arc were explored and the effects of secondary confinement on cutting quality, arc properties, and optimal process parameters were determined. By using this new method, the authors achieved better cutting quality and higher cutting speeds. Also, the possibility to reduce the heat load of the nozzle and thus enhance its service life and process stability was studied. When the nozzle diameter is 3 mm, the kerf width of the Al_2O_3 ceramic plate of 6 mm thickness is less than 4.6 mm, while the cutting speed reaches to 0.9–1.2 m/min[10]

Measured Surface hardening of steel components is traditionally done either by oxy-fuel, induction or laser hardening. Plasma arc is a new hardening technique which makes use of a small controlled stream of ionized gas to heat the material to its austenitising temperature. The heat is conducted rapidly into the bulk of the specimen causing self-quenching to occur and the formation of martens tic structures. This paper describes the optimization of the processing parameters for maximum hardened depth of ASSAB 760 (equivalent to AISI 1045) steel specimens of 6 mm thickness by using a Microplasma-50 plasma arc machine with the Taguchi method. A 4-factor 3-level (L9) orthogonal array (OA) was used in the experiment. [11]

Used Taguchi method to obtain the optimum electro deposition parameters for the synthesis of the $CuInSe_2$ thin film for solar cells. The parameters consist of annealing temperature, current density, $CuCl_2$ concentration, $FeCl_3$ concentration, H_2SeO_3 concentration, TEA amount, pH value, and deposition time. The experiments were carried out according to an $L_{18}(2^1 3^7)$ table. An X-ray diffract meter (XRD) and a scanning electron microscope (SEM) were respectively used to analyze the phases and observe the microstructure and the grain size of the $CuInSe_2$ film before and after annealing treatment. The results showed that the $CuInSe_2$ phase was deposited with a preferred plane (112) parallel to the substrate surface. The optimum parameters are as follows: current density, 7 mA/cm^2; $CuCl_2$ concentration, 10 mM; $FeCl_3$ concentration, 50 mM; H_2SeO_3 concentration, 15 mM; TEA amount, 0 mL; pH value, 1.65; deposition time, 10 min; and annealing temperature, 500°C[12]

As quality values failed to meet customers' requirements when the hot-bar soldering process (HBSP) was first introduced in the electronic manufacturing service (EMS) company, it is the intention of this study to combine quality function deployment (QFD) and the Taguchi method to analyze the produced quality characteristics and to optimize the process parameters. The product from HBSP is a gate board that transmits vertical signals in thin film transistor liquid crystal display (TFT-LCD) modules. To produce a gate board through HBSP, a film of flexible printed circuit (FPC) is soldered onto the pad of a printed circuit board (PCB) with the hot-bar (HB) which is heated by a pulse heater. [13]

The Taguchi method of experimental design is very well suited to improving the production process of synthetic bone grafts for several reasons. Firstly, the effect of many different process variables can be examined simultaneously, which ensures that beneficial factor combinations are not overlooked. Secondly, it is very efficient and easy to apply, so that it does not require large amounts of time or resources to conduct a given set of experiments. This makes it possible to conduct a series of experiments that result in continuous process improvement. Finally, using a Taguchi signal-to-noise ratio permits the concurrent optimization of the process and the reduction of process variability.[14]

Described the application of the fuzzy logic analysis coupled with Taguchi methods to optimize the precision and accuracy of the high-speed electrical discharge machining (EDM) process. A fuzzy logic system is used to investigate relationships between the machining precision and accuracy for determining the efficiency of each parameter design of the Taguchi dynamic experiments. From the fuzzy inference process, the optimal process conditions for the high-speed EDM process can be easily determined as $A_1B_1C_3D_1E_3F_3G_1H_3$. In addition, the analysis of variance (ANOVA) is also employed to identify factor B (pulse time), C (duty cycle), and D (peak value of discharge current) as the most important parameters, which account for about 81.5% of the variance.[15]

Used Taguchi method with fuzzy logic for optimizing the electrical discharge machining process with multiple performance characteristics has been reported. A multi-response performance index is used to solve the electrical discharge machining process with multiple performance characteristics. The machining parameters (the work piece polarity, pulse-on time, duty factor, open discharge voltage, discharge current and dielectric fluid) are optimized [16]

Presented an investigation on the effect and optimization of machining parameters on the kerf (cutting width) and material removal rate (MRR) in wire electrical discharge machining (WEDM) operations. The experimental studies were conducted under varying pulse duration, open circuit voltage, wire speed and dielectric flushing pressure. The settings of machining parameters were determined by using Taguchi experimental design method. The level of importance of the machining parameters on the cutting kerf and MRR is determined by using analysis of variance (ANOVA). The optimum machining parameter combination was obtained by using the analysis of signal-to-noise (S/N) ratio. [17]

A numerical control 3-D processing system was constituted for dual swirling plasma arc cutting. The effect of cutting energy parameters and operating gases on kerf characteristics was then investigated experimentally, so asto provide a reference for appropriately selecting process parameters to improve cut quality. It is shown that kerf widths reduce, and the bevel angle and the straightness increase with an increase of cutting speed and a decrease of arc current. moreover, a smaller bevel angle, together with greater straightness and more dross, exhibits on the low speed side of the cut. As the oxygen content of the operating gas decreases, kerf widths decrease and the dross increases, while the bevel angle varies slightly on the high speed side of the cut. For the pure oxygen and pure air processes, the bevel angle on the low speed side and the straightness of cut surface are the smallest, but the pure oxygen cut surface is the roughest due to the occurrence of a saw-like kerf.[18]

PROCESS VARIABLES CHAPTER 3

3.1 Gases

At least two separate (and possibly three) flows of gas are used in PAC

- Plasma gas – flows through the orifice and becomes ionized
- Shielding gas – flows through the outer nozzle and shields the molten weld from the atmosphere
- Back-purge and trailing gas – required for certain materials and applications.

These gases can all be same, or of differing composition.

3.2 Key Process Variables

- Flame cutting thickness.
- Cutting speed.
- Gas flow rate (This critical variable must be carefully controlled based upon the current, orifice diameter and shape, gas mixture, and the base material and thickness.)
- Work voltage.
- Cutting air pressure.

“STUDY OF PROCESS PARAMETERS IN PLASMA ARC MACHINING PROCESS”

4.1 Experimental Setup

The plasma cutting machine consists of:

a) Compressor

b) Plasma cutting machine

c) Plasma cutting torch

d) Torch conveyor

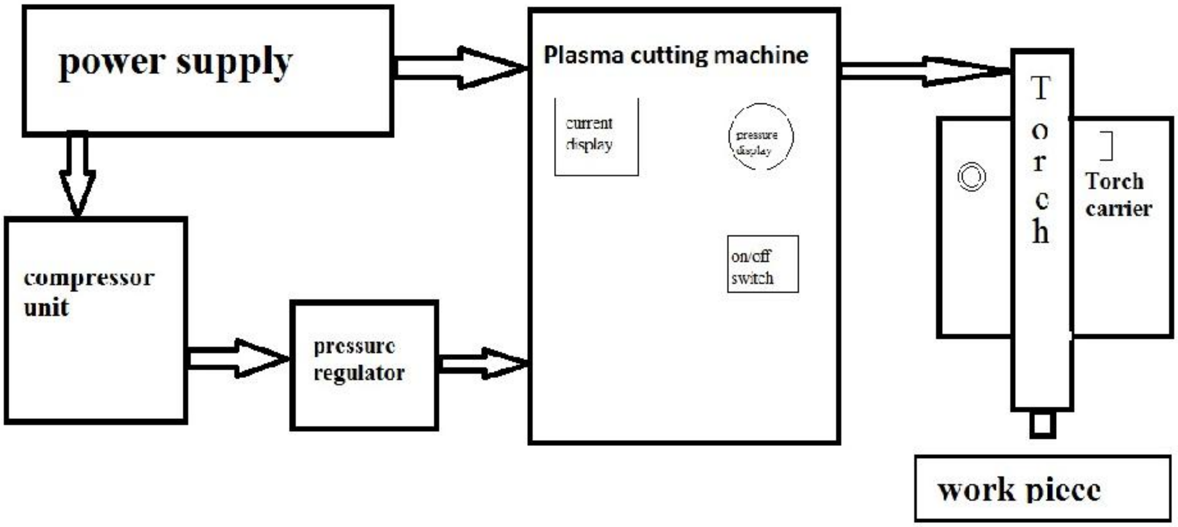


Fig. 4.1. plasma cutting system components

Fig 4.2 Actual Experimental Setup

4.1.1 Compressor

The compressor is used to supply the high presser air to the plasma cutting machine maximum pressure that can be supplied by the compressor is 200 psi. The compressor is directly attached to the plasma cutting machine, which uses the air supplied by the compressor as plasma gas and cooling gas.

4.1.2 Plasma Cutting Machine

The plasma cutting machine available is the KALI-100 model, the specifications of the machine is as follows:

Cutting capacity	32mm (fine)/50mm(course)
Input Voltage/Frequency	415V/50Hz
Open circuit Voltage	380 V (DC)
Insulation	Class A
Transformer Cooling	Forced Air
Duty Cycle	100%
Dimensions	600 mm*1125 mm*740 mm
Input Connections	RYB

Fig 4.3 Plasma Cutting Machine

4.1.3 Plasma Cutting Torch

Plasma cutting torch is the most important component of the plasma cutting machine. The air form the plasma cutting machine is supplied to the torch at a very high pressure. The torch is connected to the positive terminal of the power supply and the work piece is connect to the negative terminal as the circuit is complete the current starts to flow and the air is ionized to plasma of very high temperature about 30000 F. The material of the torch should be such that it could bear that much high temp. and the current should be connected easily.

The specification of the torch is as follows:

Plasma Gas	Air
Air Pressure	upto 80 psi
Air Flow Rate	200 LPM
Current Capacity	upto 125 A
Model	KM 3 (Machine)/ KH3
Torch Cooling	Air
Duty Cycle	100%
Torch Lead	6 m

Fig. 4.4 Plasma cutting torch

4.1.4 Torch Conveyor

The torch is mounted on the conveyor the conveyor can move to and fro to straight line. The speed of the conveyor can be controlled according to the requirements. The speed control is manual, the start and stop switch of the conveyor is mounted on the conveyor itself.

4.2 Input Parameter

1. Flame cutting thickness: 6-150mm.

2. Cutting speed: 50-4000mm/min.

3. Work voltage: 220/380V +-10% 50Hz

4. Cutting air pressure: 1.2MPa

5. Cutting oxygen pressure :< =1.0MPa.

6. Plasma Gas pressure :< =0.25MPa.

7. Work temperature :< =50 C.

4.3 Output Parameters

1. Material removal rate.

2. Surface roughness.

3. Microstructure.

4. Heat affected zone.

5. Noise level.

5.1. Taguchi Design Overview

Dr. Genichi Taguchi is regarded as the foremost proponent of robust parameter design, which is an engineering method for product design that focuses on minimizing variation and or sensitivity to noise. When used properly, Taguchi design provides a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. In robust parameter design the primary goal is to find factor settings that minimize response variation, while adjusting (or keeping) the process on target. After you determine which factors affect variation, you can try to fine settings for controllable factors that will either reduce the variation, make the product insensitive to changes in uncontrollable (noise) factors, or both, a process designed with this goal will produce more consistent output. a product designed with this goal will deliver more consistent performance regardless of the environment in which it is used. Engineering knowledge should guide the selection of factors and responses [3]. Robust parameter design is particularly suited for energy transfer processes; for example, a car's steering wheel is designed to transfer energy from the steering wheel to the wheels of the car. You should also scale control factors ad responses so that interactions are unlikely. When interactions among control factors are likely or not well understood, you should choose a design that is capable of estimating those interactions. Minitab can help you select a Taguchi design that does not confound interactions of interest with each other or may require preliminary experimentation.

The noise levels selected should reflect the parameter design uses Taguchi designs (orthogonal arrays), which allow you to analyze many factors with few runs. Taguchi designs are balanced, that is no factor is weighted more or less in an experiment, thus allowing factors to be analyzed independently of each other. Minitab provides both static and dynamic response experiments.

- In a static response experiment, the quality characteristic of interest has a fixed level.
- In a dynamic response experiment, the quality characteristic operates over a range of values and the goal is to improve the relationship between an input signal and an output response. An example of a dynamic response experiment is an automotive acceleration experiment where the input signal is the amount of pressure on the gas pedal and the output response is vehicle speed. You can create a dynamic response experiment where the input signal is the amount of pressure on the gas pedal and the output response is vehicle speed. You can create a dynamic response experiment by adding a signal factor to a design- see creating a dynamic response experiment by of robust experimentation is to find an optimal combination of control factor settings that achieve robustness. Against (insensitivity to) noise factors, Minitab calculates response tables, linear model results, and generates main effects and interaction plots for:
- Signal-to-noise radios (provide a measure of robustness) vs. the Control factors.
- Means (static design) or slopes (dynamic design vs. the control factors
- Standard deviations vs. the control factors.
- Natural log of the standard deviations vs. the control factors.

Use the results and plots to determine what factors and interactions are important and evaluate how they affect responses. To get a complete understanding of factor effects it is advisable to evaluate S/N ratios, means (static design), slopes (dynamic design), and standard deviations, Make sure that you choose an S/N ratio that is appropriate for the type of data you have and your goal for optimizing the response.

5.2. Taguchi Design Structure

A Taguchi design, or an orthogonal array, is a method of designing experiments that usually requires only a fraction of the full factorial combinations. An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be evaluated independently of all the other factors, so the effect of one factor does not influence the estimation of another factor, in robust parameter design, you first choose control factors and their levels and choose an orthogonal array appropriate for these control factors. The control factors comprise the inner array. At the same time, you determine a set of noise factors, along with an experimental design for this set of factors. The noise factors comprise the outer array. The experiment is carried out by running the complete set of noise factor settings at each combination of control factor settings (at each run. The response data from each run of the noise factors in the outer array are usually aligned in a row, next to the factors settings for that run of the control factors in the inner array. For an example, see Data for Analyze Taguchi Design. Each column in the orthogonal array represents a specific factor with two or more levels. Each row represents a run; the cell values indicate the factor settings for the run. By default, Minitab’s orthogonal array designs use the integers 1, 2, 3....to represent factors levels. If you enter factor levels, the integers 1, 2, 3...will be the coded levels for the design. The following table displays the L9 (3^4) Taguchi design (orthogonal array_. L9 means 9 runs. 3^4 means 4 factors with 3 levels each. If the full factorial design were used, it would have 3^4 = 81 runs. The L9 (3^4_ array requires only 9 runs-a fraction of the full factorial design. This table array is orthogonal; factor levels are weighted equally across the entire design. The table column represent the control factors, the table rows represent the runs. (Combination of factor levels), and each table cell represents the factor level for that run.

Experiment no	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table No.- 5.1 Experimental design using *L9* orthogonal array

RESEARCH METHODOLOGY CHAPTER 6

Since the introduction of the plasma arc cutting process in the 1950s, there has been a steady growth in its use in the metal fabrication industries for profile cutting of metallic sheets and plates. Despite superior industrial developments that have taken place, the process has received very little attention from the scientific community on any of the scientific aspects of the process, including thermal plasma generation, plasma- material interaction, liquid metal removal, and process control. The different activities that are employed in this research are categorized into two groups: analytical research and experimental research. These activities are dependent on one another. The theoretical study and experimental research are done simultaneously as shown in Fig 6.1.

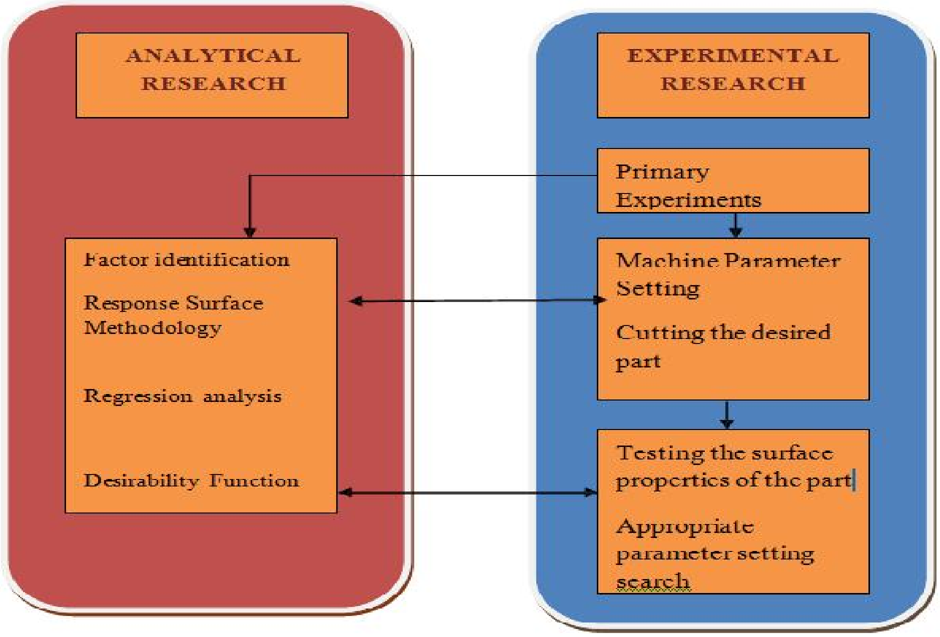


Fig 6.1. Research Methodology

6.1 Experimental Research

In the experimental research, many parts were fabricated. In addition, as part of the research, numerous experiments were conducted to find better surface quality of the cut. These include experiments with machine parameter variation (e.g., cutting pressure, voltage, cut height etc). The primary reason for experimental research was to discover or identify the factors that most affected the part quality. Primary settings for factors in conducted experiments in this stage were assigned through the one-factor-at-a-time method.

6.2 Analytical Research

The analytical research was designed by applying the Taguchi Method as the statistical tool to determine the optimum process parameters for controlling the process and determining the best performance of the plasma cutter to the target i.e. minimizing the kerf and heat effected zone. Our target is to minimize the kerf and heat effected zone so the condition of smaller is better is used in Taguchi analysis for determination for the optimum process parameters. It gives ANOVA which tells about the effect of individual parameter on the process output.

6.3 INDEPENDENT AND DEPENDANT VARIABLES

Previous research and preliminary experiments helped to identify the factors for the experiments and also to find the appropriate parameters for a better cut quality. For this purpose seven factors are selected for our new experiment. Based on the preliminary experiments and the Plasma cutter machine manuals, the following variables seem to be the most influential factors on the part quality: current, pressure, torch height, tool type, and cut direction.

6.3.1 Current

This factor was among the suggested variables by the Plasma developers (SR-100i User's Manual). Cutting power is dependent only on the type and thickness of the material being cut. The amount of variation allowed by the SR-100i User's Manual was 25A to 130A. The 30A to 50A range was used for drag tip cutting where the torch tip touches the work piece on thin plates of mild steel about 1 cm thickness.for thicker plates of mild steel the current density increases for the thickness of piece upto 6 cm the current is used in the range of 70 A to 130 A. The 70A to 130 A range was employed for standoff cutting, where the torch tips do not touch the work piece. The discrete range used for investigation was 75A, 90A, and 125A. Typical results from insufficient cutting power proved to be cuts that did not penetrate all the way through the thickness of the work piece. Whereas, typical results from too much cutting power were kerf too great, due to extreme heat, and poor cut surface quality

6.3.2 Air Pressure

Pressurized air serves two purposes in plasma cutting. The primary purpose is to supply gas to fuel the plasma reaction, and the secondary purpose is to blow melted material away while cooling the tip. Pressure was determined as a variable affecting quality by the Plasma machine Manual. Operating pressure range as given by the user manual was listed as 65 psi to 85 psi; less than 65 psi triggered a safety in the SR-100i User’s Manual and prevented operation. A maximum pressure input of 100 psi was also listed. A combination of operating range and experimentation determined that the discrete range used for investigation was 70 psi, 75 psi, and 80 psi.

6.3.3 Cut Speed

The cut speed is the speed at which the torch moves in the X-Y plane while the torch is cutting. Cut speed varies depending on material type, material thickness, and input power. Material thickness and type were constant and then cut speed was dependent only on input power. Both the cut speed and input power are input variables for the Plasma cutting machine. The Plasma cutter user manual states that the cut speed may vary by a long range for the same material. Therefore, the feasible range of speeds was found to be in between .30(m/min) 3.0 (m/min). For our analysis the range of travelling speed is taken as 1.5 (m/min), 2.0 (m/min), 2.5 (m/min).

6.3.4 Torch Height

Torch Height is the distance between the tip of the torch and the work piece. Standoff distances of 2 mm and 6 mm were proposed in the SR-100i User's Manual. The feasible range of torch height was found to be in between 2 mm and 6 mm. for uor analysis the range of torch height or stand off distance is taken as 2.5 mm, 3.2 mm, 4.0 mm.

6.4 Noise Factors

According to Arvidsson and Gremyr (2008) noise factors are those forces that cause deviation from target and are out of the control of the experimenter. These factors are simply sources of variation and have an effect on the response but their affect was uncontrollable. The noise factors in this experiment were temperature and humidity of the air. This was because the sheet metal gets heated up to different temperatures since the runs were done continuously. This was uncontrollable. So, we considered it as a noise factor. According to Suwanprateeb. J (2007), direct contact of the metal with the water or exposure to humidity degrades the material's mechanical and physical properties. The humidity in the air also affects the sheet metal and it is uncontrollable.

Machining parameter	Symbol	Level 1	Level 2	Level 3
Current (A)	A	75	90	125
Torch Travelling Speed(m/min)	B	1.5	2.0	2.5
Air Pressure (psi)	C	70	75	80
Stand-off Distance (mm)	D	2.5	3.2	4.0

Table 6.1. Summary of the variables and their levels.

Three levels are considered for four of the factors (1= low, 2 = medium and 3 = high), The Response Surface function curvature is also looked. So, this is the best way to fit a regression model which relates the response to the factor levels. Two replicates were used for design of experiment is 3^4 i.e. 81 experiments needed and if we consider that for having the best result we should take three observations at each condition then the total number of obsrevation comes out to be 81* 3= 243, the orthogonal array is used to minimize the number of runs or experiments and still obtains the maximum information which allows easy interpretation of results. Among the Orthogonal Array approaches, an L-9 Orthogonal Array is selected. All experiment settings were shown Table 6.2.

Experiment no	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 6.2 Experimental settings for the run

6.5 Approximate Analysis

In this type of analysis, the missing observation is estimated and the analysis of variance is performed with that data as it were the real data. The error degrees of freedom are reduced by one for each missing observation.

6.6 Exact Analysis

In this analysis, the missing data makes the design unbalanced. The fitted values for the observation are found from the solution to the normal equation and the ANOVA is done through a general regression significance test. This Research uses the Qualitek-4 software that excludes the missing observations from the row they are in and accordingly the regression model is adjusted.

6.7 Output Parameters and their Measurement

6.7.1 Kerf.

Kerf or the bevel angle is the deviation from the target value in terms of angle. The cutting should be perpendicular but due to high heat and air pressure the cutting is at some angle which is not desirable. Our target is to minimize this kerf angle to minimize the loss of material. The kerf is measured by using the bevel protector. The value of kerf for the different experimental settings is shown by the Table 6.3

Experiment no	A	B	C	D	Observations		
					First run	Second run	Third run
1	1	1	1	1	38	38	37
2	1	2	2	2	34	35	34
3	1	3	3	3	35	34	35
4	2	1	2	3	41	40	40
5	2	2	3	1	37	39	39
6	2	3	1	2	37	38	38
7	3	1	3	2	35	37	36
8	3	2	1	3	40	42	42
9	3	3	2	1	36	34	35

Table 6.3 kerf Response

6.7.2 Heat Affected Zone

The temperature in plasma cutting is very high and due to the conductivity of material it is conducted in the work material which result in the change in micro structure of the work material. This will affect both metallurgical as well as the physical properties of the work material. So heat affected zone should be kept minimum. The Heat Affected Zone can be determined by checking the microstructure of the material under the electronic microscope. The measured values of HAZ are shown in Table 6.4

Experiment no	A	B	C	D	Observations		
					First run	Second run	Third run
1	1	1	1	1	3.4	3.6	3.6
2	1	2	2	2	2.6	2.4	2.4
3	1	3	3	3	2	1.8	1.9
4	2	1	2	3	4.4	4.8	4.6
5	2	2	3	1	4	3.8	3.7
6	2	3	1	2	2.8	2.4	2.5
7	3	1	3	2	6.2	6.1	6.3
8	3	2	1	3	5	4.9	5.3
9	3	3	2	1	4.2	4.3	4.4

Table 6.4 Heat Affected Zone Response

6.7.3. Noise Level

The noise developed during plasma cutting is very unpleasant and uncomfortable for the operator but the control of this noise is possible upto certain extent it can’t be controlled upto a large extent.

The statistical tool used for determining the optimum process parameters is Taguchi the software which is used for calculation is Qualitek-4 software which is Automatic Design and Analysis of Taguchi Experiments. This software provides the information about the selection of taguchi design which depends on the number of process variables and the level of their variation. The design of experiment is complete in this stage. The combination of the various process variables is given after the selection of Taguchi orthogonal Array.

In our research the number of variables is four and their level is three so we have the Taguchi L9 orthogonal Array for the study. The levels of the various process variables are given as input to the software. The output parameter which is used for controlling the process is the kerf and Heat Affected Zone. Both are undesirable so we have to minimize both kerf and Heat Affected Zone. So we take the condition of smaller is better for our calculations.

The calculation will be on the basis of average of values and S/N Ratio.

7.1 Average of Values

In average of values the mean of all the trails or run is calculated then this mean or average value is used as input for further calculation. This type of calculation is done because the average value is very much close to our observed result so it gives the clear idea of the effect of various factors on the desired result.

7.2 Signal-to-Noise Ratio

In Taguchi designs, a measure of robustness used to identify control factors that reduce variability in a product or process by minimizing the effects of uncontrollable factors (noise factors). Control factors are those design and process parameters that can be controlled. Noise factors cannot be controlled during production or product use, but can be controlled during experimentation. In a Taguchi designed experiment, you manipulate noise factors to force variability to occur and from the results, identify optimal control factor settings that make the process or product robust, or resistant to variation from the noise factors. Higher values of the signal-to-noise ratio (S/N) indicate control factor settings that minimize the effects of the noise factors.

Taguchi experiments often use a 2-step optimization process. In step 1 use the S/N ratio to identify those control factors that reduce variability. In step 2, identify control factors that bring the mean to target and have little or no effect on the S/N ratio.

The signal-to-noise (S/N) ratio measures how the response varies relative to the nominal or target value under different noise conditions. You can choose from different S/N ratios, depending on the goal of your experiment. For static designs, Minitab offers four S/N ratios:

7.2.1 Noise Factor

In Taguchi designs, factors that cause variability in the performance of a system or product, but cannot be controlled during production or product use. You can, however, control or simulate noise factors during experimentation. You should choose noise factor levels that reflect the range of conditions under which the response should remain robust.

Common types of noise factors are:

External: Environmental factors, customer usage, and so on

Manufacturing variations: Part-to-part variations

Product deterioration: Degradation that occurs through usage and environmental exposure

During experimentation, you manipulate noise factors to force variability to occur, then from the results, identify optimal control factor settings that make the process or product resistant, or robust to variation from the noise factors. Control factors are those design and process parameters that can be controlled.

7.3 Kerf. Response

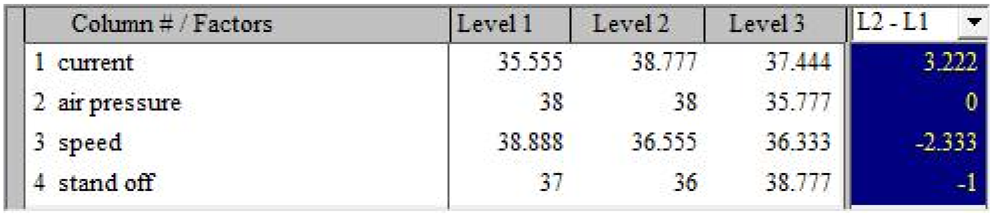
7.3.1 Analysis using Average of Results

Experiment File

Data Type	Average Value
Quality Characteristic	Smaller is better

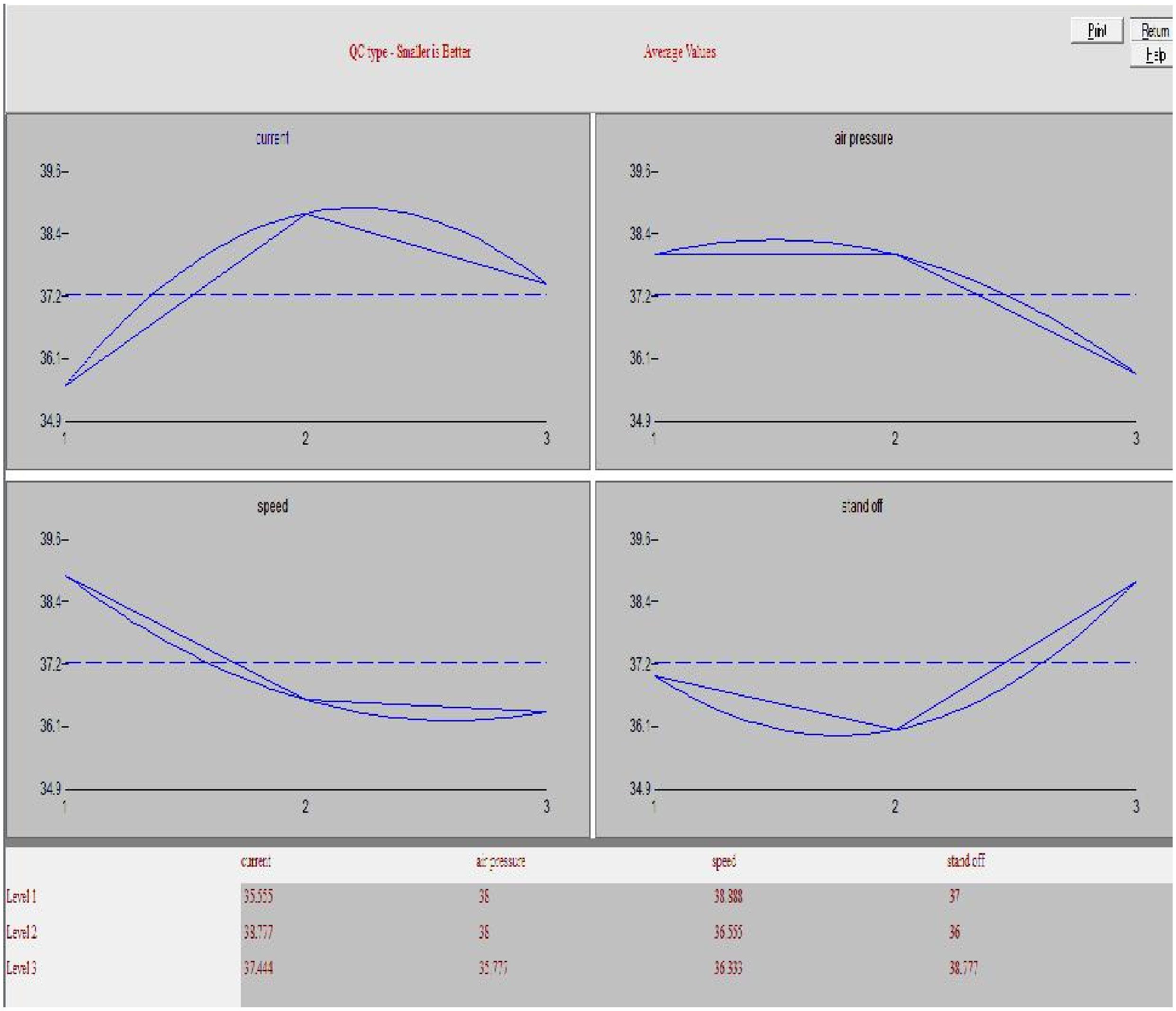
Experiment no	A	B	C	D	Observations			Average
					First run	Second run	Third run	
1	1	1	1	1	38	38	37	37.66
2	1	2	2	2	34	35	34	34.33
3	1	3	3	3	35	34	35	34.66
4	2	1	2	3	41	40	40	40.33
5	2	2	3	1	37	39	39	38.33
6	2	3	1	2	37	38	38	37.66
7	3	1	3	2	35	37	36	36
8	3	2	1	3	40	42	42	41.33
9	3	3	2	1	36	34	35	35

Table - 7.1 Average Value of Experimental Run (KAV)



Column # / Factors	Level 1	Level 2	Level 3	L2 - L1
1 current	35.555	38.777	37.444	3.222
2 air pressure	38	38	35.777	0
3 speed	38.888	36.555	36.333	-2.333
4 stand off	37	36	38.777	-1

Table - 7.2 Main Effects (KAV)

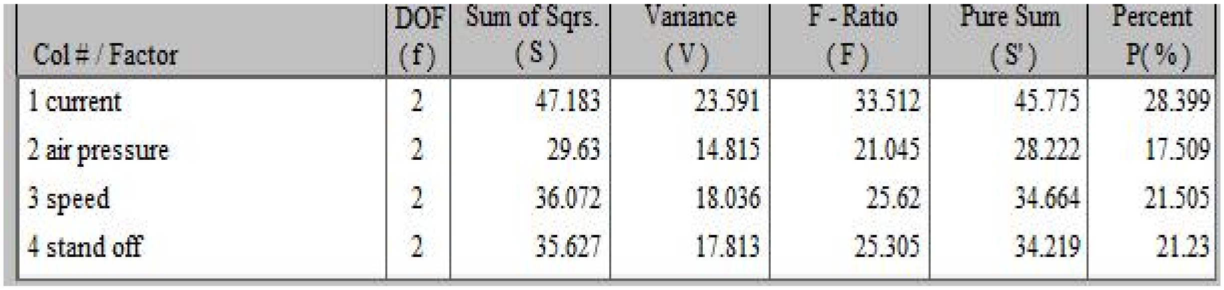


QC type - Smaller is Better

Average Values

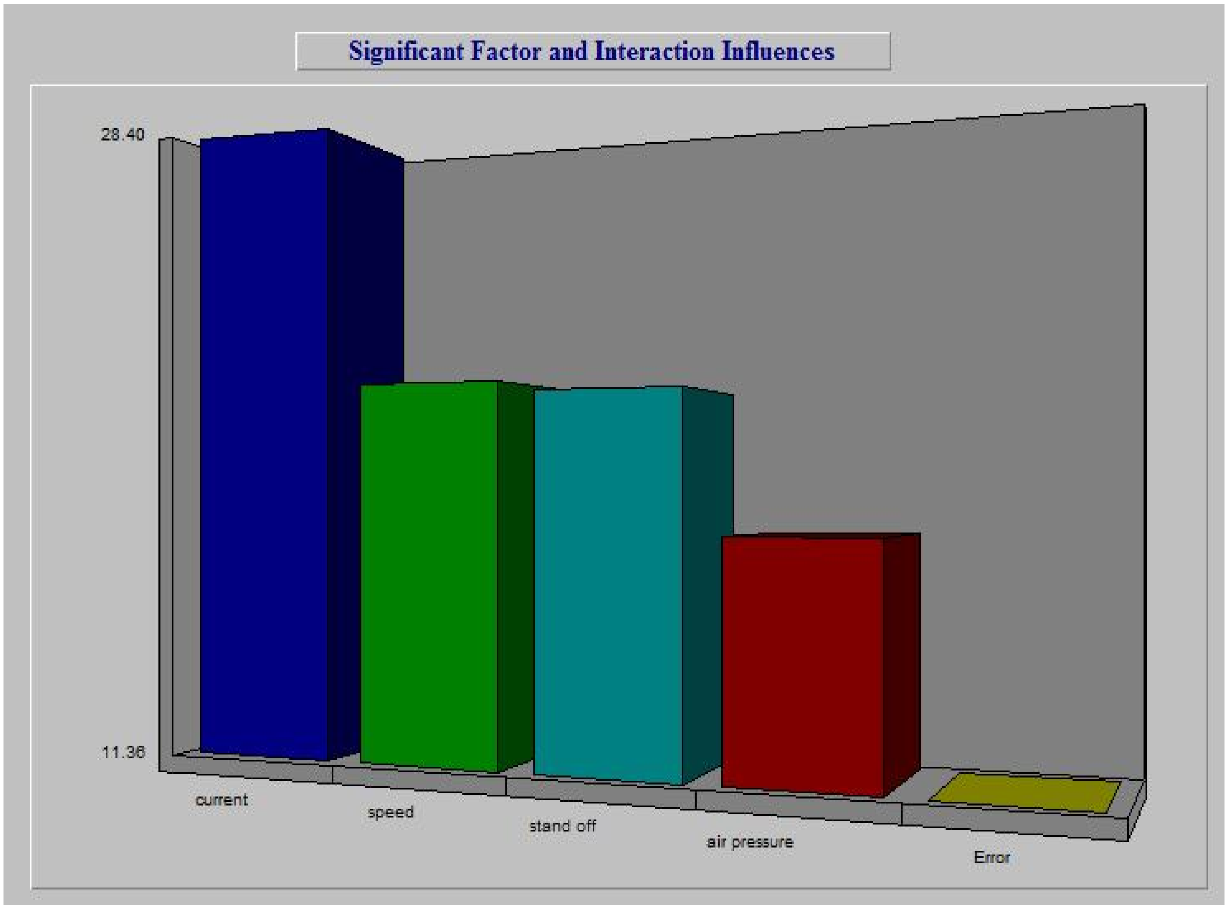
	current	air pressure	speed	stand off
Level 1	35.555	38	38.888	37
Level 2	38.777	38	36.555	36
Level 3	37.444	35.777	36.333	38.777

Multiple Graphs of Main Effects (KAV)

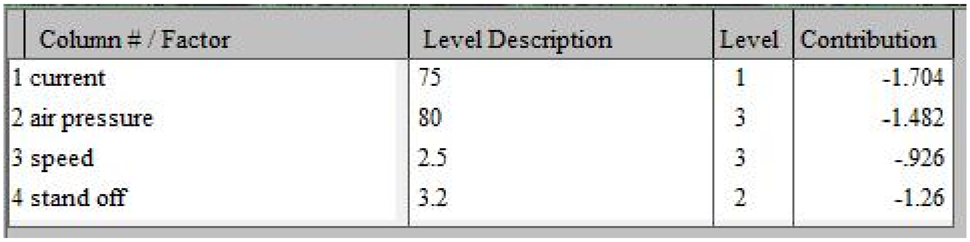


Col # / Factor	DOF (f)	Sum of Sqrs. (S)	Variance (V)	F - Ratio (F)	Pure Sum (S')	Percent P(%)
1 current	2	47.183	23.591	33.512	45.775	28.399
2 air pressure	2	29.63	14.815	21.045	28.222	17.509
3 speed	2	36.072	18.036	25.62	34.664	21.505
4 stand off	2	35.627	17.813	25.305	34.219	21.23

Table - 7.3 ANOVA Table (KAV)

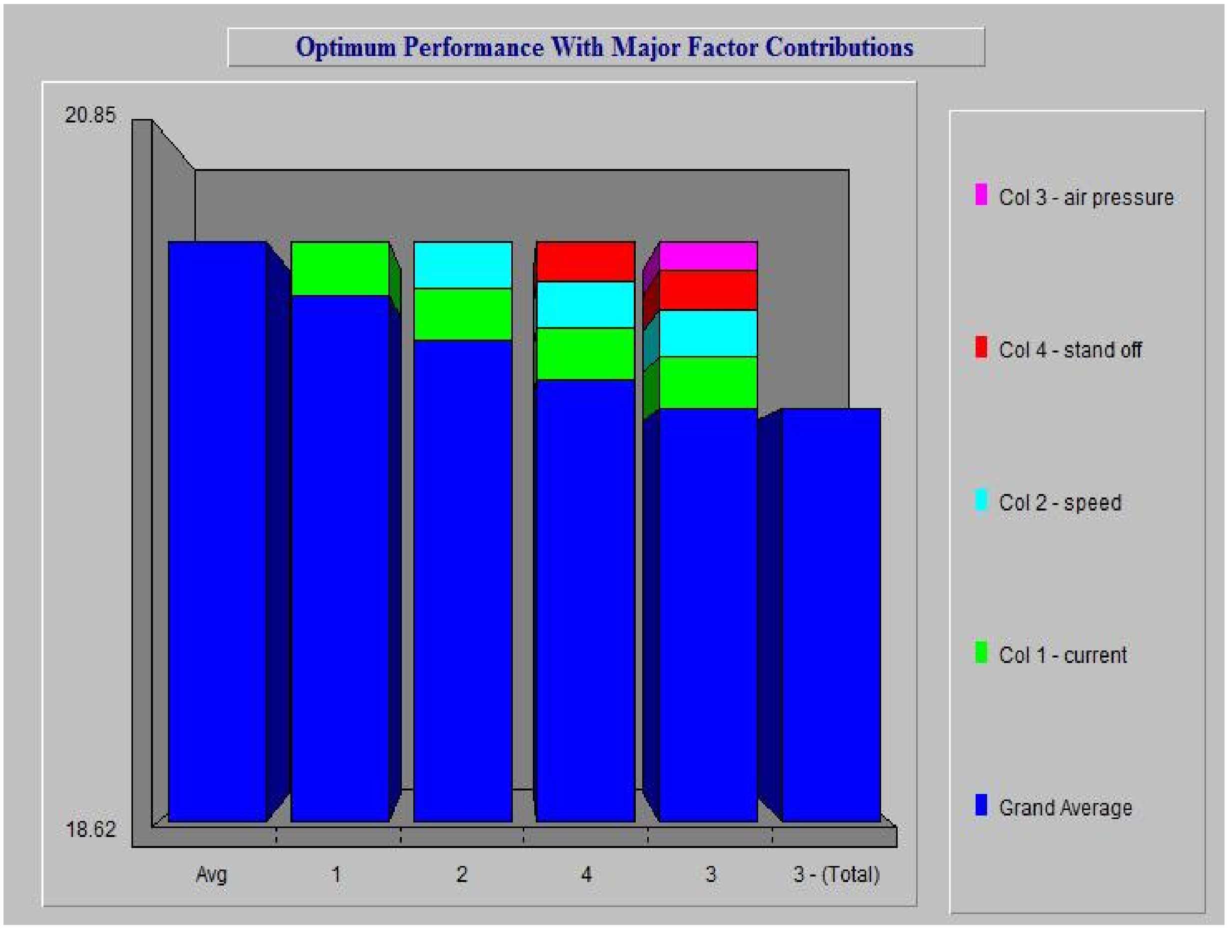


Relative Influence of Factors and Interactions (KAV)



Column # / Factor	Level Description	Level	Contribution
1 current	75	1	-1.704
2 air pressure	80	3	-1.482
3 speed	2.5	3	-.926
4 stand off	3.2	2	-1.26

Table - 7.4 Optimum Conditions and Performance (KAV)



Factor Contribution-stacked Graph (KAV)

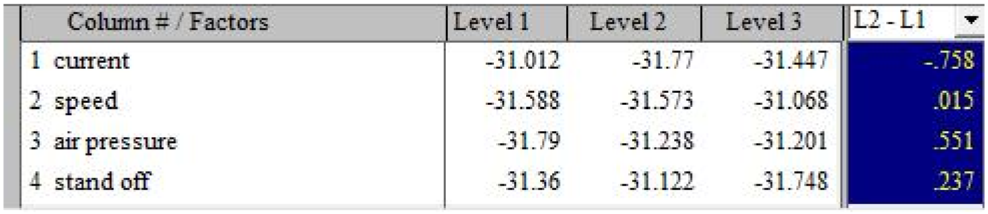
7.3.2 Analysis using S/N Ratio

Experiment File

Data Type	S/N Ratio
Quality Characteristic	Smaller is better

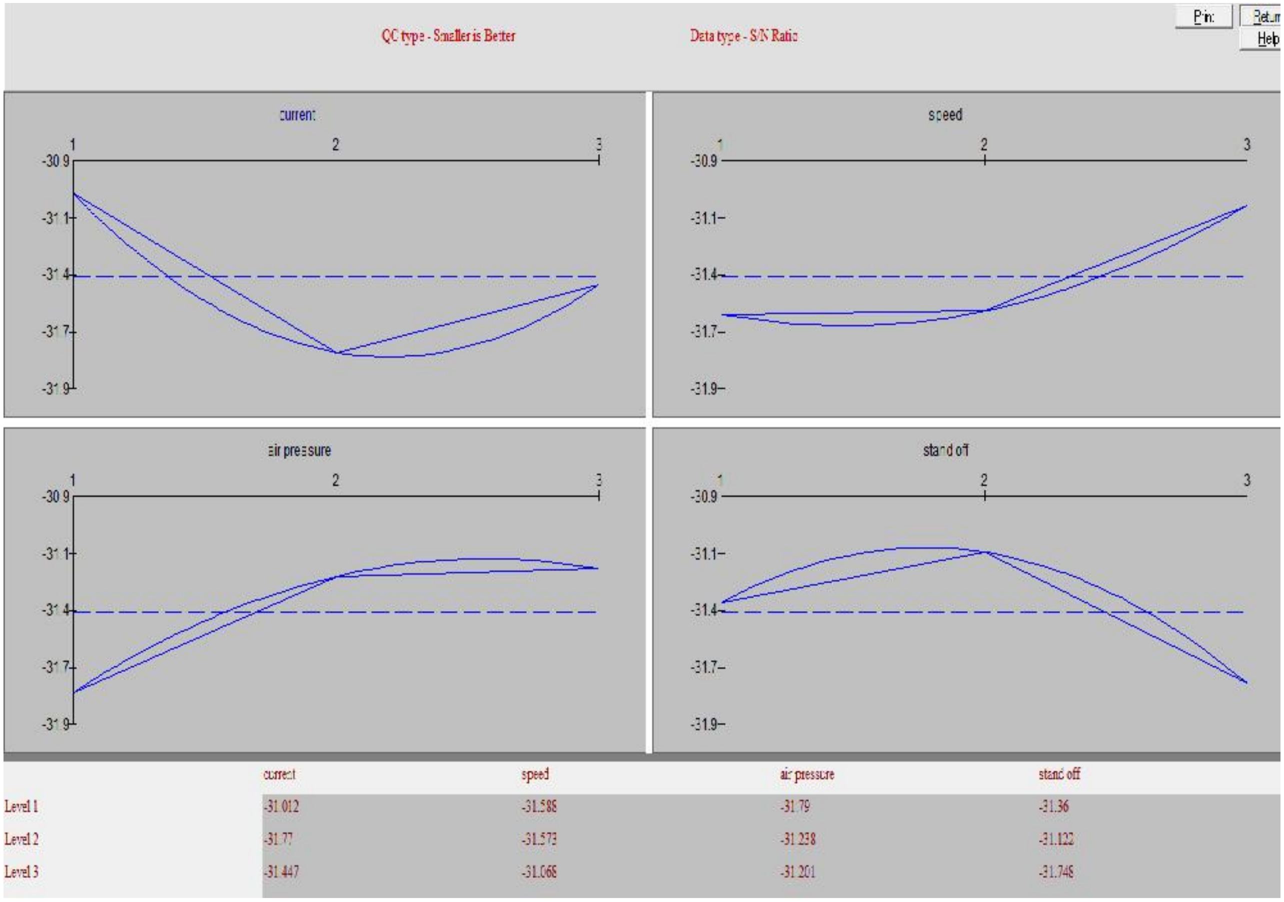
Experiment no	A	B	C	D	Observations			S/N Ratio
					First run	Second run	Third run	
1	1	1	1	1	38	38	37	-31.52
2	1	2	2	2	34	35	34	-30.716
3	1	3	3	3	35	34	35	-30.8
4	2	1	2	3	41	40	40	-32.114
5	2	2	3	1	37	39	39	-31.675
6	2	3	1	2	37	38	38	-31.52
7	3	1	3	2	35	37	36	-31.129
8	3	2	1	3	40	42	42	-32.329
9	3	3	2	1	36	34	35	-30.884

Table - 7.5 S/N Ratio of Experiment Run (KS/NR)



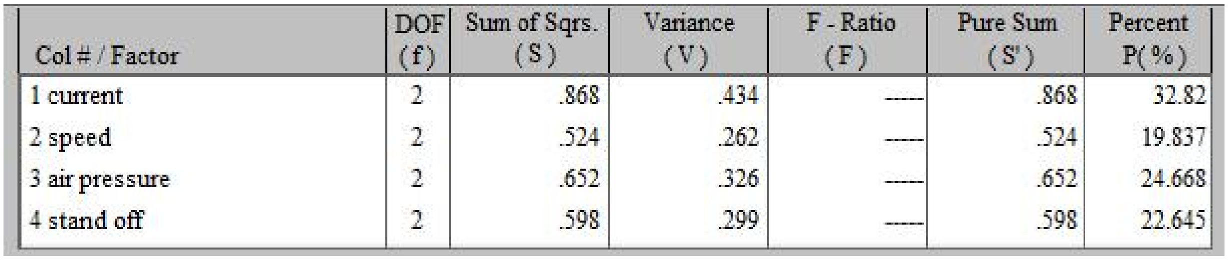
Column # / Factors	Level 1	Level 2	Level 3	L2 - L1
1 current	-31.012	-31.77	-31.447	-.758
2 speed	-31.588	-31.573	-31.068	.015
3 air pressure	-31.79	-31.238	-31.201	.551
4 stand off	-31.36	-31.122	-31.748	.237

Table -7.6 Main Effects (KS/NR)



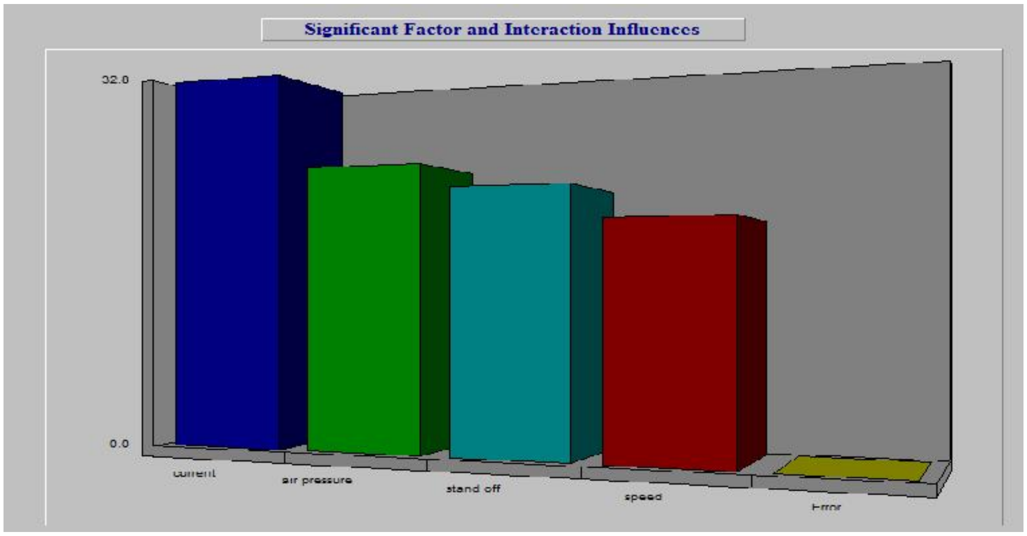
	current	speed	air pressure	stand off
Level 1	-31.012	-31.588	-31.79	-31.36
Level 2	-31.77	-31.573	-31.238	-31.122
Level 3	-31.447	-31.068	-31.201	-31.748

Multiple Graph of main Effects (KS/NR)

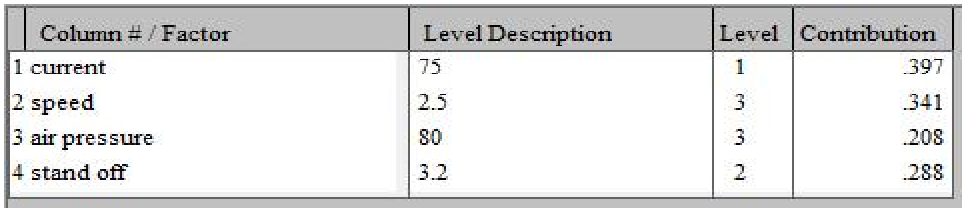


Col # / Factor	DOF (f)	Sum of Sqrs. (S)	Variance (V)	F - Ratio (F)	Pure Sum (S')	Percent P(%)
1 current	2	.868	.434	-----	.868	32.82
2 speed	2	.524	.262	-----	.524	19.837
3 air pressure	2	.652	.326	-----	.652	24.668
4 stand off	2	.598	.299	-----	.598	22.645

Table -7.7 ANOVA Table (KS/NR)



Relative Influence of Factors and Interactions (KS/NR)



Column # / Factor	Level Description	Level	Contribution
1 current	75	1	.397
2 speed	2.5	3	.341
3 air pressure	80	3	.208
4 stand off	3.2	2	.288

Table – 7.8 Optimum condition of performance (KS/NR)

7.4 Heat Affected Zone Response

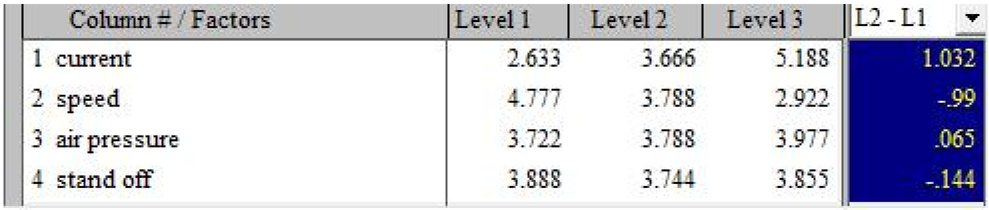
7.4.1 Analysis using Average of Results:

Experiment File

Data Type	Average Value
Quality Characteristic	Smaller is better

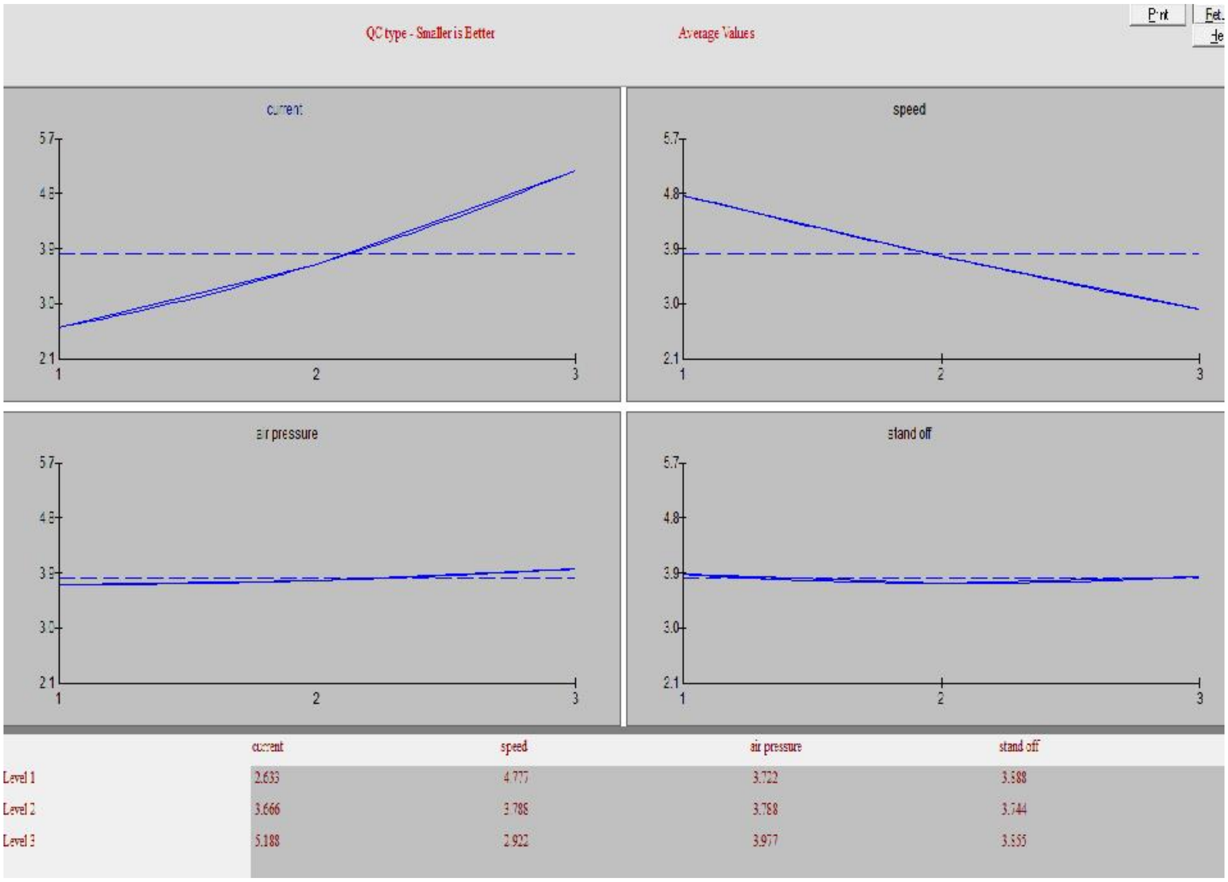
Experiment no	A	B	C	D	Observations			Average
					First run	Second run	Third run	
1	1	1	1	1	3.4	3.6	3.6	3.533
2	1	2	2	2	2.6	2.4	2.4	2.466
3	1	3	3	3	2	1.8	1.9	1.9
4	2	1	2	3	4.4	4.8	4.6	4.6
5	2	2	3	1	4	3.8	3.7	3.833
6	2	3	1	2	2.8	2.4	2.5	2.556
7	3	1	3	2	6.2	6.1	6.3	6.199
8	3	2	1	3	5	4.9	5.3	5.066
9	3	3	2	1	4.2	4.3	4.4	4.3

Table 7.9 Average Value of Experiment Run (HAZAV)



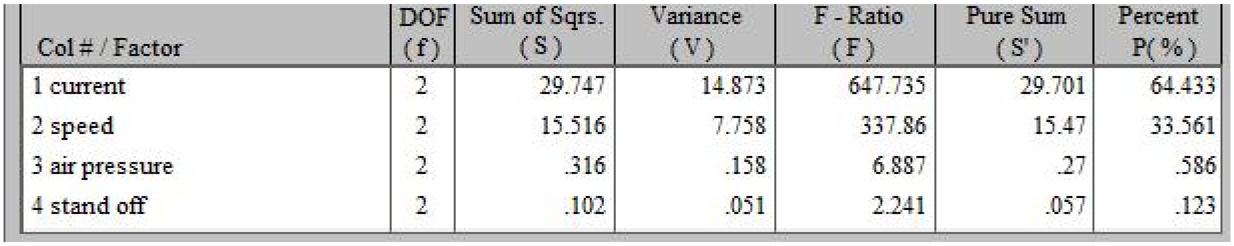
Column # / Factors	Level 1	Level 2	Level 3	L2 - L1
1 current	2.633	3.666	5.188	1.032
2 speed	4.777	3.788	2.922	-.99
3 air pressure	3.722	3.788	3.977	.065
4 stand off	3.888	3.744	3.855	-.144

Table - 7.10 Main Effects (HAZAV)



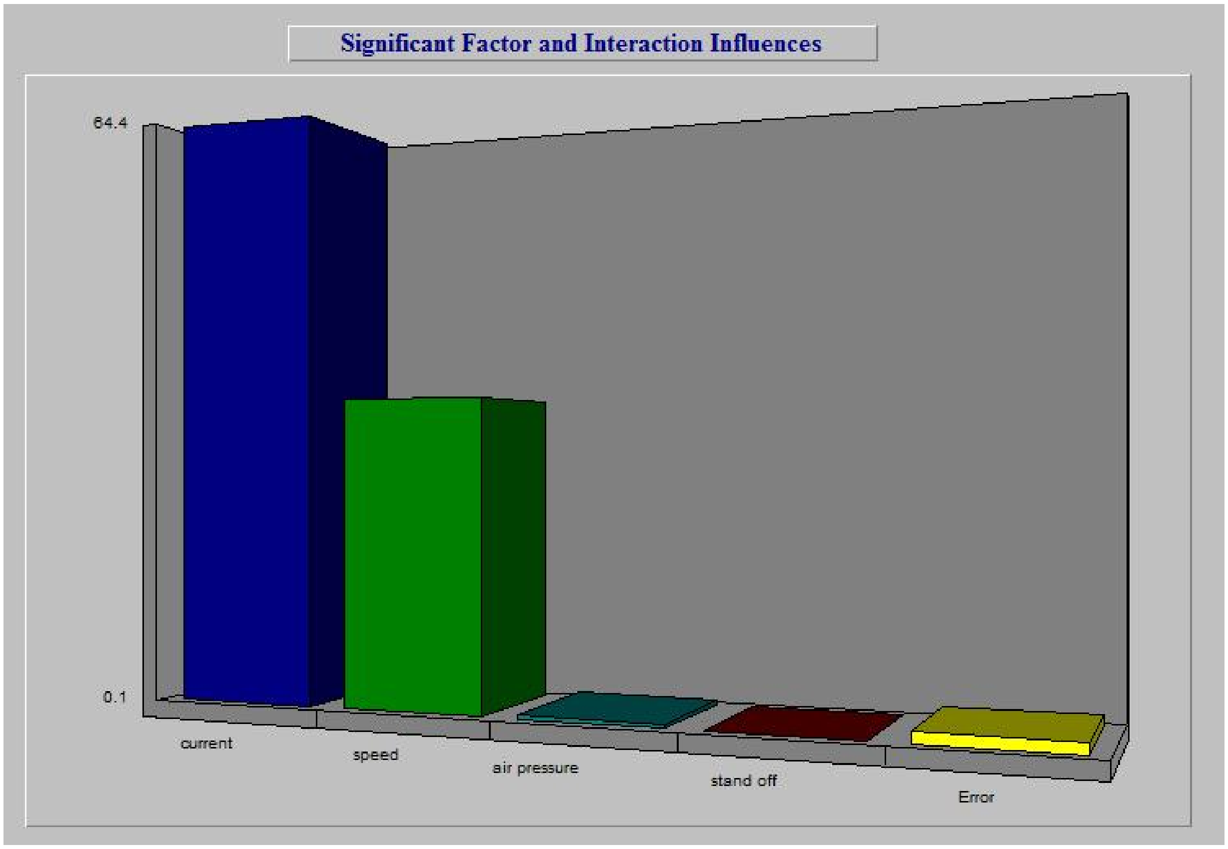
	current	speed	air pressure	stand off
Level 1	2.633	4.777	3.722	3.888
Level 2	3.666	3.788	3.788	3.744
Level 3	5.188	2.922	3.977	3.855

Multiple Graph of Main Effects (HAZAV)

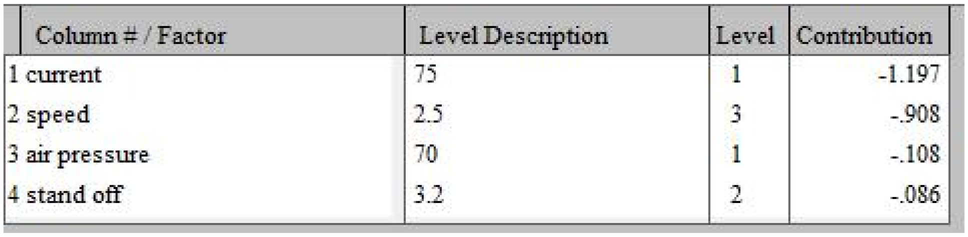


Col # / Factor	DOF (f)	Sum of Sqrs. (S)	Variance (V)	F - Ratio (F)	Pure Sum (S')	Percent P(%)
1 current	2	29.747	14.873	647.735	29.701	64.433
2 speed	2	15.516	7.758	337.86	15.47	33.561
3 air pressure	2	.316	.158	6.887	.27	.586
4 stand off	2	.102	.051	2.241	.057	.123

Table – 7.11 ANOVA Table (HAZAV)

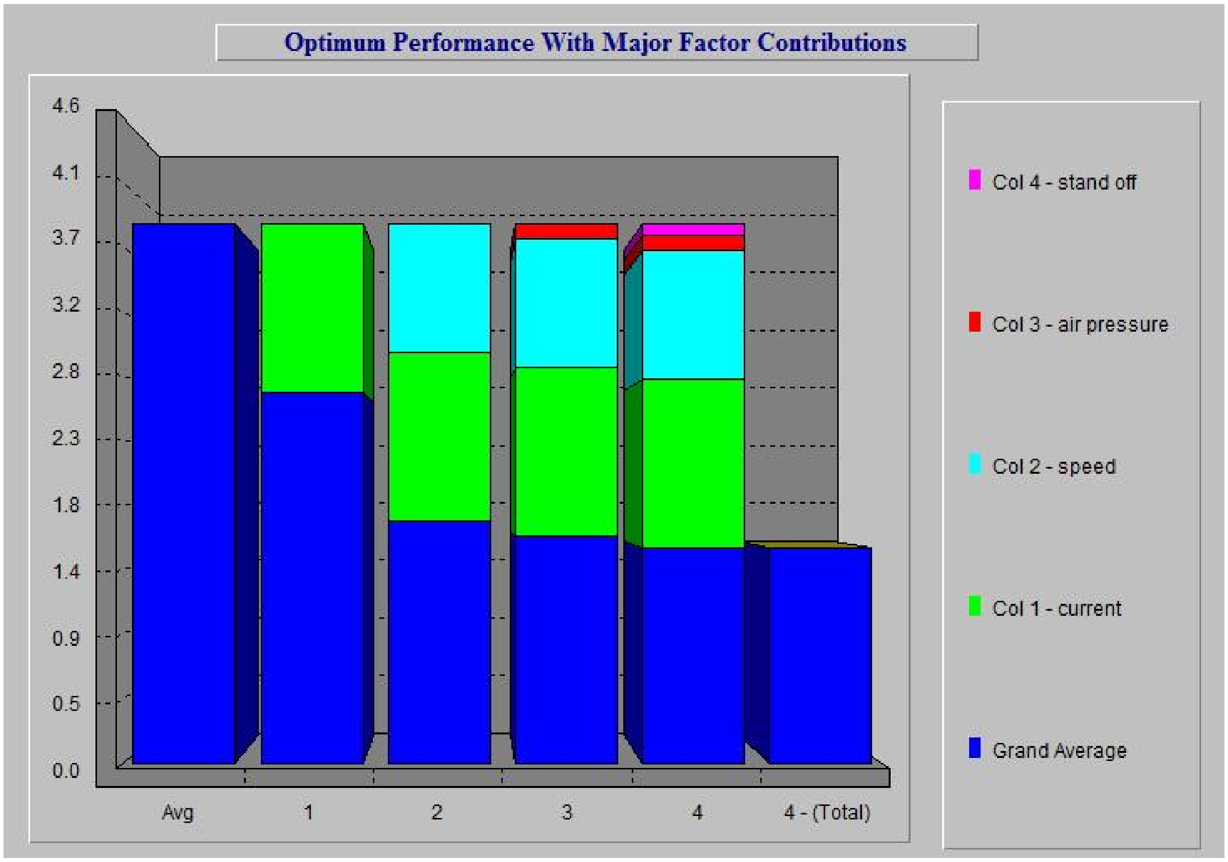


Relative Influence of Factors and interactions (HAZAV)



Column # / Factor	Level Description	Level	Contribution
1 current	75	1	-1.197
2 speed	2.5	3	-.908
3 air pressure	70	1	-.108
4 stand off	3.2	2	-.086

Table -7.12 Optimum condition and performance (HAZAV)



Factors contribution- stacked group (HAZAV)

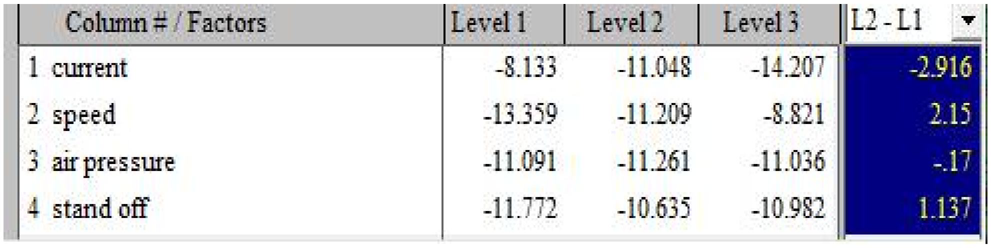
7.4.2 Analysis using S/N Ratio

Experiment File”

Data Type	S/N Ratio
Quality Characteristic	Smaller is better

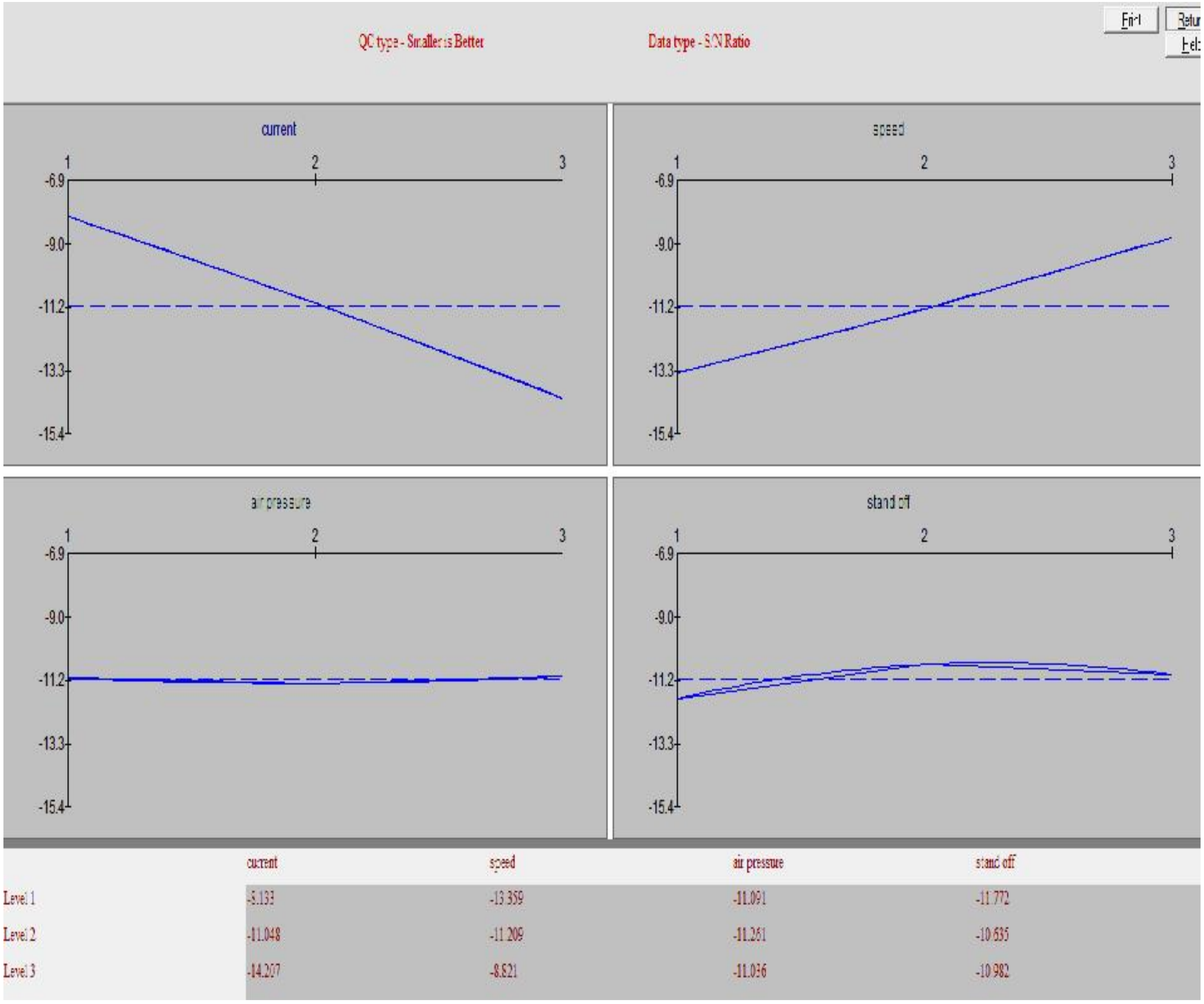
Experiment no	A	B	C	D	Observations			S/N Ratio
					First run	Second run	Third run	
1	1	1	1	1	3.4	3.6	3.6	-10.967
2	1	2	2	2	2.6	2.4	2.4	-7.849
3	1	3	3	3	2	1.8	1.9	-5.584
4	2	1	2	3	4.4	4.8	4.6	-13.261
5	2	2	3	1	4	3.8	3.7	-11.667
6	2	3	1	2	2.8	2.4	2.5	-8.2207
7	3	1	3	2	6.2	6.1	6.3	-15.849
8	3	2	1	3	5	4.9	5.3	-14.1
9	3	3	2	1	4.2	4.3	4.4	-12.671

Table 7.13 Average Value of Experiment Run (HAZS/NR)



Column # / Factors	Level 1	Level 2	Level 3	L2 - L1
1 current	-8.133	-11.048	-14.207	-2.916
2 speed	-13.359	-11.209	-8.821	2.15
3 air pressure	-11.091	-11.261	-11.036	-.17
4 stand off	-11.772	-10.635	-10.982	1.137

Table – 7.14 Main Effects(HAZS/NR)

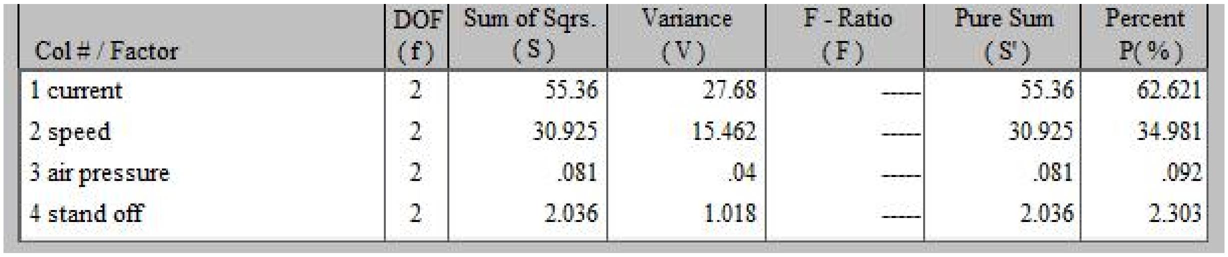


QC type - Smaller is Better

Data type - S/N Ratio

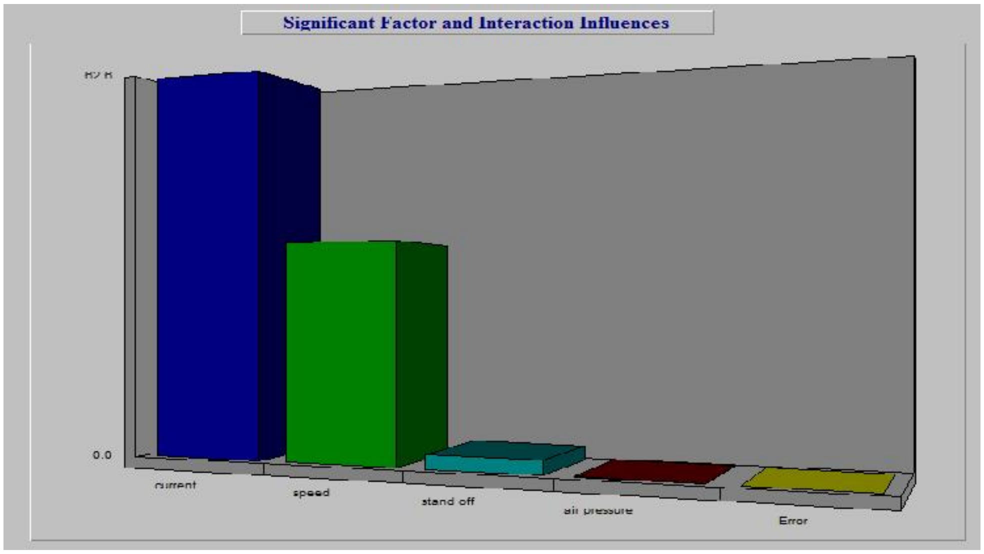
	current	speed	air pressure	stand off
Level 1	-8.133	-13.359	-11.091	-11.772
Level 2	-11.048	-11.209	-11.261	-10.635
Level 3	-14.207	-8.821	-11.036	-10.982

Multiple Graphs of Main Effects (HAZS/NR)

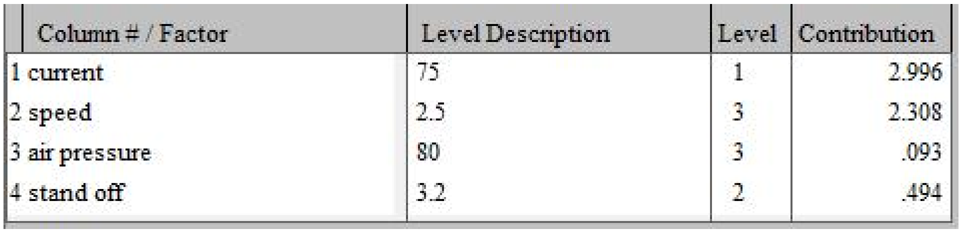


Col # / Factor	DOF (f)	Sum of Sqrs. (S)	Variance (V)	F - Ratio (F)	Pure Sum (S')	Percent P(%)
1 current	2	55.36	27.68	-----	55.36	62.621
2 speed	2	30.925	15.462	-----	30.925	34.981
3 air pressure	2	.081	.04	-----	.081	.092
4 stand off	2	2.036	1.018	-----	2.036	2.303

Table - 7.15 ANOVA Table (HAZS/NR)



Relative Influence of Factors and Interactions (HAZS/NR)



Column # / Factor	Level Description	Level	Contribution
1 current	75	1	2.996
2 speed	2.5	3	2.308
3 air pressure	80	3	.093
4 stand off	3.2	2	.494

Table - 7.16 Optimum condition and performance (HAZS/NR)

7.5 Observations

In this research the calculation is done on the basis of average of values and S/N ratio. The Main Effect of all the parameters is calculated. The Multiple Graph is plotted which shows the effect of variation of the parameters on a single plot. Moreover it gives the idea about the extent upto which a factor effect the process graphically. ANOVA gives the percentage effect of all the factors i.e. it tells about the percentage or parameters according to their effect on the process. The finally the optimum conditions and performance is given which tell about the optimum value of process variables which gives the best performance according to the desired constraints i.e. smaller is better in our case.

7.5.1 Observation of kerf using Average of Results

The effect is current is maximum on the process after that speed and stand off distance have more or less same effect air pressure have minimum effect on the process.

The optimum values of each parameter is given by table 7.4, the optimum current is 75 A optimum air pressure is 80 psi, optimum torch travelling speed is 2.5 m/min, optimum stand-off distance is 3.2 mm of having minimum kerf which is calculated by average of results.

7.5.2 Observation of kerf using S/N Ratio

The effect is current is maximum on the process after that speed and stand off distance have more or less same effect air pressure have minimum effect on the process.

The optimum values of each parameter is given by table 7.8, the optimum current is 75 A optimum air pressure is 80 psi, optimum torch travelling speed is 2.5 m/min, optimum stand-off distance is 3.2 mm of having minimum kerf which is calculated by average of results.

7.5.3 Observation Heat Affected Zone Response using Average of Results

The effect is current is maximum on the process which is more the 60% after that speed have a effect of about 33% and stand off distance and air pressure have minimum effect on the process. Their combined effect is less the 1% on the process

The optimum values of each parameter is given by table 7.12, the optimum current is 75 A optimum air pressure is 70 psi, optimum torch travelling speed is 2.5 m/min, optimum stand-off distance is 3.2 mm of having minimum kerf which is calculated by average of results.

7.5.2 Observation Heat Affected Zone Response using S/N Ratio:

The effect is current is maximum on the process which is more the 60% after that speed have a effect of about 33% and stand off distance and air pressure have minimum effect on the process. Their combined effect is less the 3% on the process

The optimum values of each parameter is given by table 7.16, the optimum current is 75 A optimum air pressure is 80 psi, optimum torch travelling speed is 2.5 m/min, optimum stand-off distance is 3.2 mm of having minimum kerf which is calculated by average of results.

Conclusions CHAPTER 8

In this research, the optimum parameter settings were identified for the plasma cutting process by using Taguchi L9 orthogonal array, the number of runs required of this design is 9, in this array we have four variables having three leves so the number of run required if Taguchi orthogonal array is not used are 3^4 i.e. 81 runs. So by using Taguchi method we have reduced our number of runs.

The main parameters which effect the process are current, air pressure, stand-off distance, and torch travelling speed. Three levels of these parameters are considered in increasing order. The entire process in this study was conducted for mild steel sheet with 10 mm thickness.

The statistical tool used for determining the optimum process parameters is Taguchi the software which is used for calculation is Qualitek-4 software which is Automatic Design and Analysis of Taguchi Experiments. This software provides the information about the selection of Taguchi design which depends on the number of process variables and the level of their variation.

The current has maximum effect on the process after that torch travelling speed and stand-off distance and air pressure have minimum effect on the process.

The overall optimum values of each parameter give the calculation is, the optimum current is 75 A optimum air pressure is 80 psi, optimum torch travelling speed is 2.5 m/min, optimum stand-off distance is 3.2 mm of having minimum kerf and Heat Affected Zone.

Future Scope

CHAPTER 9

A similar study can be done to investigate other popular sheet metal thicknesses. Also, that would be interesting (and costly) if one can conduct a new similar study by incorporating sheet metal thickness as one of the factors. So, one could take this in to consideration and make a related study.

As many of the responses measured were qualitative, one can use new measuring equipment and measure the responses quantitative and can make a similar study. Another study can also be made using other materials such as wood and asbestos etc.

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