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# Aanalysis of Process Parameters of Plasma Arc Cutting Using Design of Experiment

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**ABSTRACT**

***Plasma Arc Cutting (PAC) is a widely used thermal cutting process for electrically conductive materials, offering high cutting speeds and precision. This study focuses on analyzing the effects of critical process parameters namely arc current, cutting speed, gas pressure, and torch height on key performance outcomes such as material removal rate (MRR), surface roughness, kerf width, and heat-affected zone (HAZ). The Design of Experiment (DOE) approach, specifically the Taguchi method, was employed to systematically plan and analyze the experiments. Experimental results were evaluated using statistical tools such as Analysis of Variance (ANOVA) and Signal-to-Noise (S/N) ratio analysis to identify the most significant factors and optimize process performance. The findings demonstrate that arc current and cutting speed have the most prominent impact on MRR and surface finish, while torch height significantly influences kerf characteristics. The study concludes that DOE is a robust and efficient methodology for optimizing PAC parameters to enhance productivity and cut quality.***

***Keyword:** Plasma Arc Cutting (PAC), Design of Experiments (DOE), Taguchi Method, Process Optimization, Arc Current, Cutting Speed, Gas Pressure, Torch Height, Material Removal Rate (MRR), Surface Roughness.*

## 1. INTRODUCTION

The plasma cutter which does the cutting is wider and more highly temperatured than an oxy-acetylene flame, so its kerfs width is smaller and can produce cleaner cuts. Because of this, plasma cutting is well suited for sheet metal cutting, a purpose for which oxy-acetylene cutting torch is not especially suitable as it deposit a large amount of slag to the edges. If you are reading this by the light of a fluorescent lamp you are seeing plasma at work.It is ionized by a high voltage across electrodes at the ends of the tube and carries an electric current that makes the plasma to radiate which then makes the phosphor coating on the inner surface of the tube to emit light.

The plasma arc is the consequence of the electrical arcs heating of any gas to a very high temperature so that its atoms are ionized (an electrically charged gas resulting from an unequal number of electrons to protons) and allowing it to be electrically conductive. The fourth state of matter, plasma, appears and acts like a high temperature gas but with a significant difference; it is electrically conductive.

## 2. LITERATURE REVIEW

Boby Joseph and Mathew (2012) [1] studied the effect of input parameters on kerf characteristics and found that arc current and cutting speed significantly affect kerf width and taper.

Rajesh and Senthilkumar (2016) [2] applied the Taguchi method to optimize PAC parameters for mild steel. Their study concluded that cutting speed has the most significant effect on surface roughness.

Sathiesh Kumar et al. (2017) [3] used RSM to model and optimize PAC parameters. They developed quadratic regression models to predict responses and identified optimal cutting conditions for minimizing kerf width and roughness.

Yadav and Bajaj (2018) [4] implemented GRA to optimize multiple quality characteristics simultaneously, achieving an optimal trade-off between surface quality and productivity.

Patel and Pandya (2020) [5] combined RSM and desirability function analysis for optimizing PAC on stainless steel, highlighting the interaction effects among process parameters.

## 3. MAJOR COMPONENT USED

**3.1 Plasma Cutting Torch:** Usually made of copper with inserts of hafnium or zirconium, the electrode serves as the cathode and is the origin point of the electric arc. The plasma cutting torch is the core component of the Plasma

Arc Cutting (PAC) system, designed to generate and direct a high-temperature plasma arc used for cutting electrically conductive materials. It functions by forcing a gas□such as air, nitrogen, or argon□through a narrow nozzle while simultaneously applying a high-voltage electrical current to ionize the gas.

Fig : 3.1 Plasma Cutting Torch

### 3.2 Power Supply Unit (PSU):

The Power Supply Unit (PSU) in a Plasma Arc Cutting (PAC) system is a crucial component responsible for providing the electrical energy needed to generate and sustain the plasma arc. It delivers a steady direct current (DC) or alternating current (AC), depending on the system's design, which is required to ionize the gas and create the plasma. The PSU is typically equipped with advanced features such as pulse width modulation (PWM) to regulate the arc's current, ensuring a stable and controlled plasma jet. This modulation helps in maintaining consistent energy output, which is essential for achieving high-quality cuts and reducing the heat-affected zone (HAZ) on the material.


**Fig : 3.2 Power Supply Unit (PSU)**

### 3.3 Gas Supply System:

The Gas Supply System in Plasma Arc Cutting (PAC) is integral to the creation and maintenance of the plasma jet, which is essential for the cutting process. The system delivers a steady flow of plasma-forming gases such as air, oxygen, nitrogen, or argon-hydrogen mixtures, depending on the material being cut and the desired quality of the cut. The gas is fed through the torch at specific pressures and flow rates, ensuring that the plasma arc remains stable and focused. Oxygen, for instance, is commonly used for cutting carbon steel as it enhances the cutting speed and produces a cleaner edge. Nitrogen, on the other hand, is preferred for cutting stainless steel or aluminum as it helps reduce oxidation and prevents dross formation. The gas also plays a critical role in cooling the torch and protecting the electrode and nozzle from excessive heat.

### 3.4 CNC and Motion Control System:

Additionally, modern CNC systems can include features like automatic height control (THC), which adjusts the torch's distance from the workpiece in real-time based on feedback from the arc voltage, maintaining optimal cutting conditions throughout the process. The integration of real-time monitoring and feedback loops ensures that the system can adapt to material variations, maintaining consistent cutting performance even during extended production runs. Overall, the CNC and motion control system significantly enhances the efficiency, precision, and flexibility of plasma cutting, making it essential for both simple and complex cutting applications.

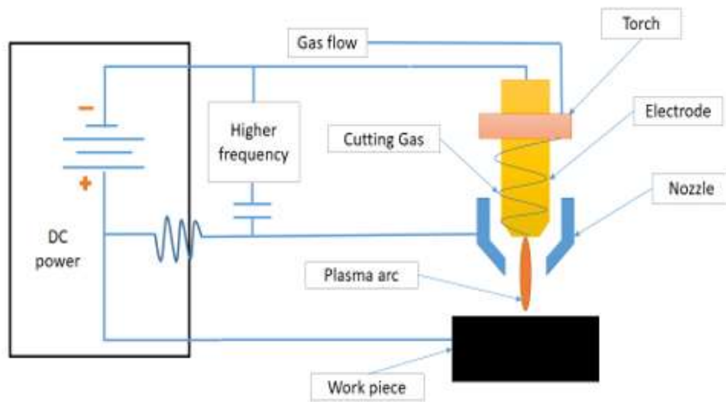


Fig : 3.3 Gas Supply System

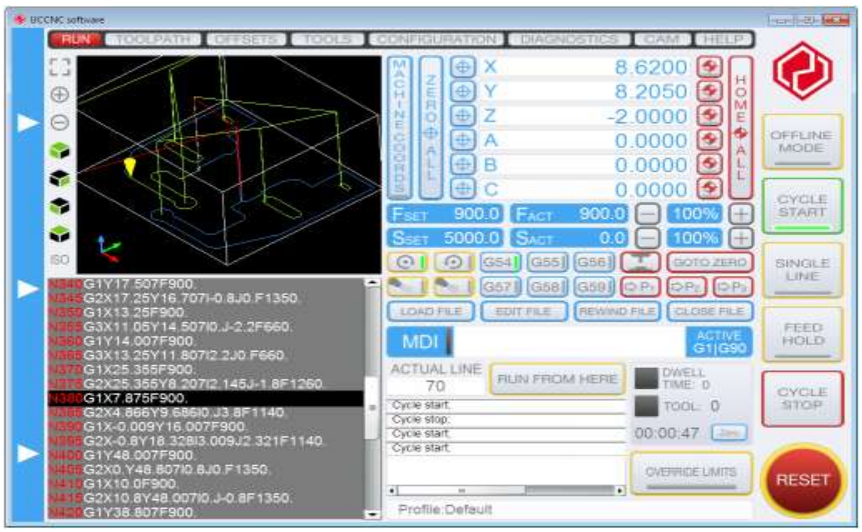


Fig : 3.4 CNC and Motion Control System

## 3.5 Electrode and Nozzle Assembly :

The Electrode and Nozzle Assembly is one of the most critical parts of the plasma cutter torch, directly responsible for initiating and shaping the plasma arc that performs the cutting. The electrode, typically made from copper and embedded with a high-melting-point material like hafnium or zirconium, serves as the cathode where the electric arc is generated. When a high-voltage current passes through the electrode and interacts with the flowing gas, it ionizes the gas and forms a plasma arc. The nozzle, usually made from heat-resistant copper alloys, surrounds the electrode and constricts the plasma arc through a narrow orifice. This constriction significantly increases the arc's energy density and focuses it into a fine, high-velocity jet capable of melting and blowing away the metal in its path.

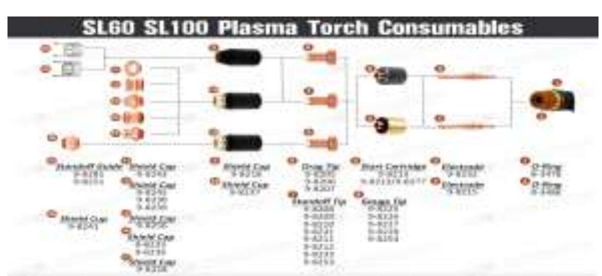


Fig : 3.4 Electrode and Nozzle Assembly

### 3.6 The Cooling System:

The Cooling System in a plasma cutting torch is essential for managing the intense heat generated during the cutting process and for protecting the internal components, especially the electrode and nozzle, from thermal damage. Plasma arcs can reach temperatures exceeding 20,000°C, which can quickly degrade torch components if not properly cooled. Most industrial plasma torches use a water-based closed-loop cooling system, where deionized water is circulated through internal channels around the electrode and nozzle. This system absorbs and transfers heat away from critical areas, helping to maintain consistent operating temperatures and prevent overheating.

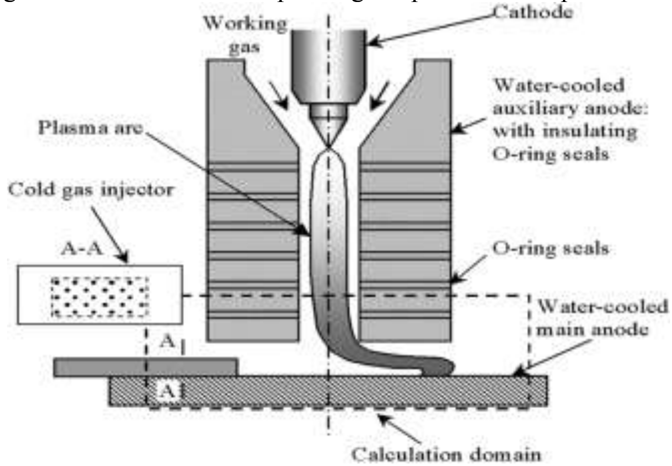


Fig : 3.6 The Cooling System

### 4. Results Analysis and Optimization:

**Material Removal Rate (MRR) Optimization:** In a study on AISI 1020 mild steel, the Taguchi L27 orthogonal array method was employed to analyze the effects of four parameters: cutting current, speed, gas pressure, and stand-off distance. The results indicated that an optimal cutting current of 85 A produced a kerf width of 2.246 mm and a material removal rate of 151.119 g/min.

**Surface Roughness and Gas Pressure:** For EN-45A material, another research utilized the Taguchi L16 orthogonal array to assess the impact of cutting speed, current, stand-off distance, and plasma gas pressure on surface roughness. The findings revealed that gas pressure significantly influences surface finish, with an optimal setting of 10 bar achieving a surface roughness of 2.98 µm.

**Kerf Width and Cutting Speed:** A study focusing on aluminum alloy EN AW-5083 applied Response Surface Methodology (RSM) to determine the effects of cutting speed, arc current, and cutting height on kerf width. The analysis showed that both cutting speed and arc current play significant roles in determining kerf width, with higher values leading to increased width.

### 5. CONCLUSIONS

Objective of this research is to determine optimal condition of Plasma Arc Cutting Machine for maximum MRR and minimum Surface Roughness (Ra). For this 16 specimens of Stainless Steel material were prepared which were readily and economically available in scrap yard of Fabrication Division of BHEL, Bhopal. Mechanical properties of Stainless Steel (316L) are provided in appendix B .Machining process is done on Plasma Arc Cutting Machine number B/0/2163 which is available in Fabrication Division of BHEL, Bhopal. I took MRR and Surface Roughness (Ra) as two most critical outputs.

According to review of literature Gas Pressure, Cutting Speed, Current Flow Rate and Arc Gap were treated as most crucial parameters. Taguchi method has been utilized for conducting minimum number of experiments for doing it. For it L16 orthogonal array has been utilized. Results obtained from experiments and different response graph for MRR and SR (Ra) have been determined and there optimal value have been used.

## 5. ACKNOWLEDGEMENT

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The present study successfully analyzed the influence of key process parameters□such as arc current, cutting speed, gas pressure, and torch height□on the performance of Plasma Arc Cutting using the Design of Experiment (DOE) methodology. Through systematic experimentation and statistical analysis, it was found that parameters like arc current and cutting speed significantly impact material removal rate and surface quality, while gas pressure and torch height play critical roles in controlling kerf width and the extent of the heat-affected zone. The use of DOE, particularly Taguchi or factorial design, proved to be an effective tool in identifying optimal parameter combinations and understanding interaction effects among variables. These findings can contribute to improved process efficiency, better quality of cut, and reduced operational costs in industrial applications. Future work can explore advanced optimization techniques or machine learning integration for further enhancement.

## 6. REFERENCES

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