Plasma Arc Machining: A Review

Parth Lad[1], Vaibhav Wani[2], Pranit Mehata[3]

[1,2]Diploma Students, Department of Mechanical Engineering, St. John College of Engineering and Management (St. John Polytechnic), Palghar, Maharashtra, India, 401404
[3]Lecturer, Department of Mechanical Engineering, St. John College of Engineering and Management (St. John Polytechnic), Palghar, Maharashtra, India, 401404

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Abstract – This paper presents an idea about plasma arc cutting process which was developed for difficult to machine materials in order to overcome the inefficiency and ineffectiveness of conventional machining method when it come to complex shape and work piece. Technology today in metal cutting process require high quality cut surfaces and good dimensional correctness without further operation. Plasma arc cutting process does high temperature and high velocity contracted arc via amount of gas between the electrode and the work material to be engrave.

***Key Words*: Plasma Arc Cutting**

1. INTRODUCTION

The three states of matter are solid, liquid and gases. The fourth state of matter is obtained when gases are heated to temperatures about 5500°C. At this temperature, the gases are partially ionized and exist in the form of mixture of free electrons, positively charged ions and neutral atoms. This mixture is termed as Plasma. When a gas is heated, then the number of collision between the atoms increases. Due to this the gas ionize, (i.e. the atoms are stripped-off their outer electron) which results in electron and ions. The electron thus produced, in turn, collide with atoms, increase their kinetic energy and ionize them so that more electrons and ions are produced. Thus, the plasma has an ability to conduct electricity due to the presence of electrons. When the gas is completely ionized, then the temperature of the central part of the plasma is between 11000°C to 28000°C. When such an ionized gas is directed on the workpiece through a high velocity jet, the metal is removed by melting. This plasma is used for the metal removal process. The plasma arc machining process is used for cutting alloy steels, stainless steel, cast iron, copper, nickel, titanium, and aluminum, etc.

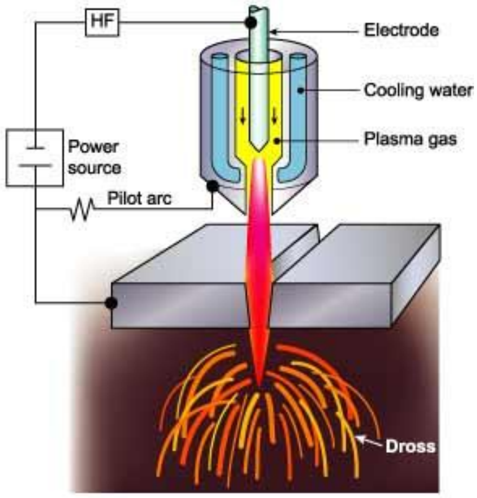

Fig -1: Plasma Arc Machining

2. WORKING

When a high velocity jet of plasma is directed on the workpiece surface by means of plasma arc cutting torch, the metal from the workpiece melts which results in to the machining of the workpiece. The contentious attack of electron on workpiece which transfer the heat energy of plasma on the workpiece causes the workpiece to melt. The melting occur due to Convective heat transfer from high temperature plasma.

3. CHARACTERISTICS OF PAM

1. Technique of metal removing: Heating, melting, and vaporizing by using plasma.
2. Workpiece material: All materials that conduct electricity.
3. Tool: Plasma jet
4. Velocity of plasma jet: 500 m /s
5. Power range: 2 to 220 kW
6. Current: As high as 600 amp.
7. Voltage: 40 – 250 V
8. Cutting speed: 0. 1 to 7 m / min
9. Metal removal rate: 145 cm^3 /min

4. PROCESS SET-UP OF PAM

1. Plasma Arc Cutting Torch
2. Tool & Workpiece
3. Gas supply unit
4. Cooling Mechanism
5. Power Supply unit

1. **Plasma Arc Cutting Torch:** A plasma cutting torch consists of tungsten electrode fitted in small chamber. The electrode is given to negative terminal. There is small converging nozzle at the end of torch. Due to this velocity of plasma increases.

2. **Tool & Workpiece:** The electrode connected to negative terminal of power supply acts as cathode. Nozzle is made anode by connecting to the positive terminal through resistor. The workpiece to be machined is connected to positive terminal.

3. **Gas supply unit:** it consists of gas cylinder, regulators and gas supply hoses. The commonly used gases are argon or nitrogen or the mixture of two. For certain useful purposes, a percentage of hydrogen may be added. The choice of the gas depends upon the material to be cut, economics and the quality of the cut edge desired. The flow rate of the gas varies directly with the thickness of the workpiece. Typical gas flow rate is 2 to 11 m^3/hr.

4. **Cooling Mechanism:** As we know that hot gases continuously come out of nozzle so there are chances of its overheating. A water jacket is used to surround the nozzle to avoid its overheating.

5. **Power Supply Unit:** A D.C. power supply of 400 V, 200 KW and upto 10000 A is supplied to the nozzle. When supply is made ON, a strong arc is struck between the electrode and the nozzle and then gas is forced into the chamber. When the gas molecules collide with the high velocity electrons of the arc, plasma is formed. This plasma is forced through the nozzle (anode) onto the workpiece.

The heat produced from this jet of plasma is sufficient to raise the workpiece temperature above its melting point and high velocity gas stream effectively blows the molten metal away.

5. MODES OF OPERATIONS

There are two modes of operations

a. Transferred type.

b. Non-transferred type.

1. In the transferred arc mode, the current is transferred from the tungsten electrode inside the torch through the orifice to the workpiece and back to the power supply.

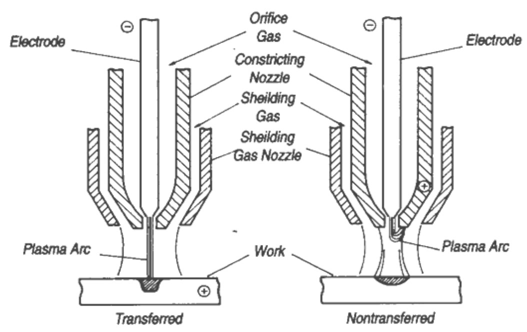

Fig -2: Modes of Operations

2. In the non-transferred mode, the current flow is from the electrode inside the torch to the nozzle containing the orifice and back to the power supply. It is used for plasma spraying or generating heat in non-metals.

6. WORKING OF PAM

1. When a D.C power is given to the circuit, a strong arc is produced between the electrode (cathode) and the nozzle (anode).
2. A gas usually hydrogen (H2) or Nitrogen (N2) is passed into the chamber.
3. This gas is heated to a sufficiently high temperature of the order of 11,000°C to 28,000°C by using an electric arc produced between the electrode and the nozzle.
4. In this high temperature, the gases are ionized and a large amount of thermal energy is liberated.
5. This high velocity and high-temperature ionized gas (plasma) is directed on the workpiece surface through the nozzle.
6. This plasma jet melts the metal of the workpiece and the high-velocity gas stream effectively blows the molten metal away.

7. The heating of workpiece material is not due to any chemical reaction, but due. to the continuous attack of plasma on the workpiece material. So, it can be safely used for machining of any metal including those which can be subjected to the chemical reaction.

7. SELECTION OF GASES

The selection of a particular gas for use in this process mainly depends on the expected quality of surface finish on the work material and economic consideration. The gases used in this process, should not affect the electrode or the workpiece to be machined. The commonly used gases and gas mixtures are given in the following table.

Sr. No.	Gases	Work Material
1.	Nitrogen-Hydrogen, Argon-Hydrogen	Stainless steel & Nonferrous metals
2.	Nitrogen-Hydrogen, Compressed air	Carbon & alloy steel, cast iron
3.	Nitrogen, Nitrogen-Hydrogen, Argon-Hydrogen	Aluminium, Magnesium

8. CONTROLLING PARAMETERS

1. **Stand-off distance:** Increase in stand - off distance reduces the depth of penetration and hence narrows the cut width at the bottom. The stand – off distance depends on the thickness of the metal to cut. The typical value of stand – off distance varies from 5 mm to 10 mm.

2. **Cutting speed:** increase in cutting speed reduces the depth of immersion of the plasma jet, leading to narrowing of the cut in the lower portion. Decrease in the cutting speed will cause the opening of the cut at the bottom of the workpiece.

3. **Gas:** the gas flow rate is directly proportional to the thickness of material. The selection of a particular gas depends on the quality of cut and the economics.

9. ADVANTAGES OF PAM

1. It can cut any material irrespective to its hardness and even non-conductive material like concrete.
2. Cutting rate of PAM is high.
3. It can cut carbon steel upto 10 times faster than any oxy-fuel cutting.
4. It can be used for rough turning operations of any material.
5. Due to the high speed of cutting, the deformation of sheet metal is reduced while the width of the cut is minimum and the surface quality is high.
6. This process is finding ever increasing application because it gives the highest temperature available for many practical sources.

10. DISADVANTAGES OF PAM

1. Protection of noise is necessary.
2. Heat affected zone is more.
3. Initial cost of equipment is high.
4. Scale formation or oxidation takes place so, it requires shielding.
5. The work surface may undergo metallurgical changes.
6. Safety precautions are necessary for operator and people working nearby.

11. APPLICATIONS OF PAM

1. It is used for cutting alloy steels, stainless steel, cast iron, copper, nickel, titanium, aluminum, and alloy of copper and nickel, etc.
2. It is used for profile cutting.
3. It is successfully used for turning and milling of hard to machine materials.
4. It can be used for stack cutting, shape cutting, piercing, and underwater cutting.
5. Uniform thin film spraying of refractory materials on different metals, plastics, ceramics are also done by plasma arcs.
6. It us used for manufacturing of automotive and rail road components.
7. Used to cut hot extrusions to desire length.

12. VARIOUS PAM PROCESSES

1. Conventional Plasma Arc Cutting
2. Air Plasma Arc Cutting
3. Dual-flow Plasma Arc Cutting
4. Under Water Plasma Arc Cutting

1. **Conventional Plasma Arc Cutting:** Arc is constricted by a nozzle only; no shielding gas is added. Cutting gas is tangentially injected to the

electrode. The swirling action of the gas causes the cooler portions of the gas to move radially outwards forming the protective boundary layer on the inside of the nozzle bore. This helps prevent damage to the nozzle and extends its life.

Fig -3: Conventional Plasma Arc Cutting.

2. **Air Plasma Arc Cutting:** Air plasma arc cutting was introduced in early 1960s for cutting mild steel. Oxygen in air provides additional energy from the exothermic reaction with molten steel, boosting cutting speeds about 25%. Process can also be used to cut stainless steel and aluminum; the cut surface will be heavily oxidized and thus can be unacceptable for some applications.

3. **Dual-flow Plasma Arc Cutting:** Dual-flow Plasma Arc Cutting is slight modification of conventional PAC. It incorporates most of the features of conventional PAC but adds a secondary shielding gas around the nozzle. The cutting gas is usually nitrogen the shielding gas is selected according to metal to be cut. Cutting speeds are slightly better than those of conventional PAC on mild steel, but the cut quality is not acceptable for some application. Cutting speeds are slightly better than those of conventional PAC on mild steel, but the cut quality is not acceptable for some applications. Cutting speed and quality on stainless steel and aluminium are essentially the same as with conventional PAC.

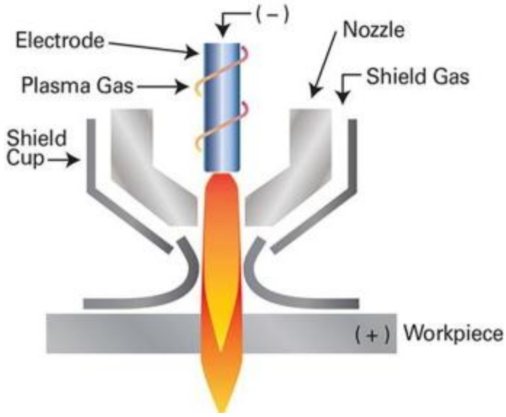

Fig -4: Dual-flow Plasma Arc Cutting

4. **UNDERWATER PLASMA ARC CUTTING:** Underwater PAC is suited to numerically (NC) shaped cutting and produces a noise level of 85 dB or less under normal operating conditions. In comparison, conventional PAC typically produces noise levels in the range of 105 to 115 dB. Underwater cutting also nearly eliminates ultra violet radiation and fumes. Steel plate being cut is supported on the cutting table with the top surface of the plate 2 to 3 inches underwater.

Fig -5: Underwater Plasma Arc Cutting.

13. CONCLUSION

In the latest field of technology respect to welding and machining, plasma arc welding and machining have a huge success. Plasma arc machining (PAM) is one of the widely used unconventional machining method that is capable of producing the complex shapes. There are certain process parameters such as gas pressure, cutting speed, arc voltage, arc current, standoff distance and gas flow rate that affect the quality distinctiveness of plasma cut like bevel angle, heat affected zone (HAZ), kerf generated and surface finish. Due to its improved weld quality and increased weld output it is been used for precision welding of surgical instruments, to automatic repair of jet engine blades to the manual welding for repair of components in the tool, die and mould industry. PAM and its assisted processes as well as optimization techniques, which made some new research scopes in the PAM. But due to its high equipment expense and high production of ozone, its been outnumbered by other advance welding equipments like laser beam welding and electron beam welding. Developments in modeling techniques have made new research scopes in the PAM and improves the performance of PAM process

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AUTHORS

Parth R. Lad, pursuing Diploma in Mechanical Engineering from St. John Polytechnic, Palghar. He is interested in Manufacturing Processes.

Vaibhav A. Wani, pursuing Diploma in Mechanical Engineering from St. John Polytechnic, Palghar. He is interested in Manufacturing Processes.

Pranit P. Mehta, working as Lecturer in Department of Mechanical Engineering St.John Polytechnic, Palghar. He has completed Masters in Design Engineering. He has published 3 research paper. He is interested in Design, thermal and manufacturing