ATME College of Engineering

Introduction to Non-Traditional Machining BME405A

Plasma Arc Machining (PAM)

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Module - 4

ELECTRICAL DISCHARGE MACHINING (EDM)

- Introduction, mechanism of metal removal, EDM equipment: spark erosion generator (relaxation type),
- Dielectric medium-its functions & desirable properties, electrode feed control system.
- Flushing types; pressure flushing, suction flushing, side flushing, pulsed flushing.
- EDM process parameters: Spark frequency, current & spark gap, surface finish, Heat Affected Zone.
- Advantages, limitations & applications of EDM
- Electrical discharge grinding, Traveling wire EDM.

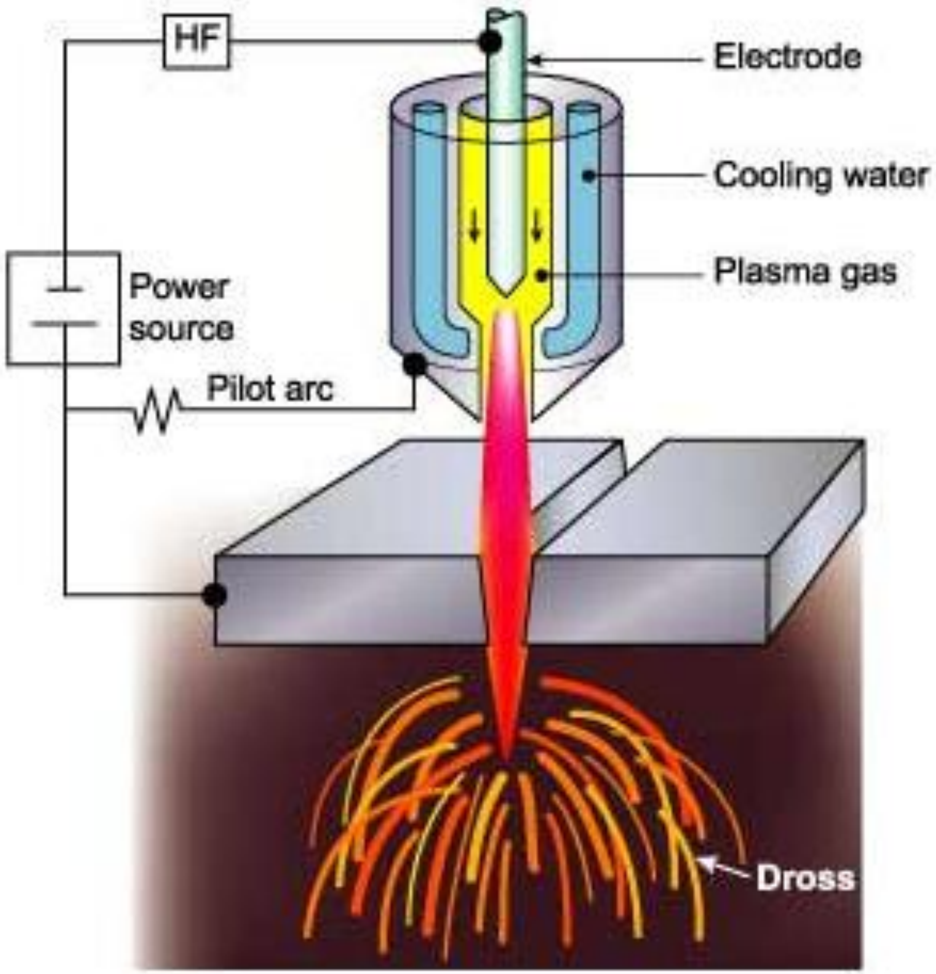
PLASMA ARC MACHINING (PAM)

- Introduction, non-thermal generation of plasma
- Equipment mechanism of metal removal
- Plasma torch
- Process parameters, process characteristics.
- Safety precautions
- Applications, advantages and limitations.

Plasma

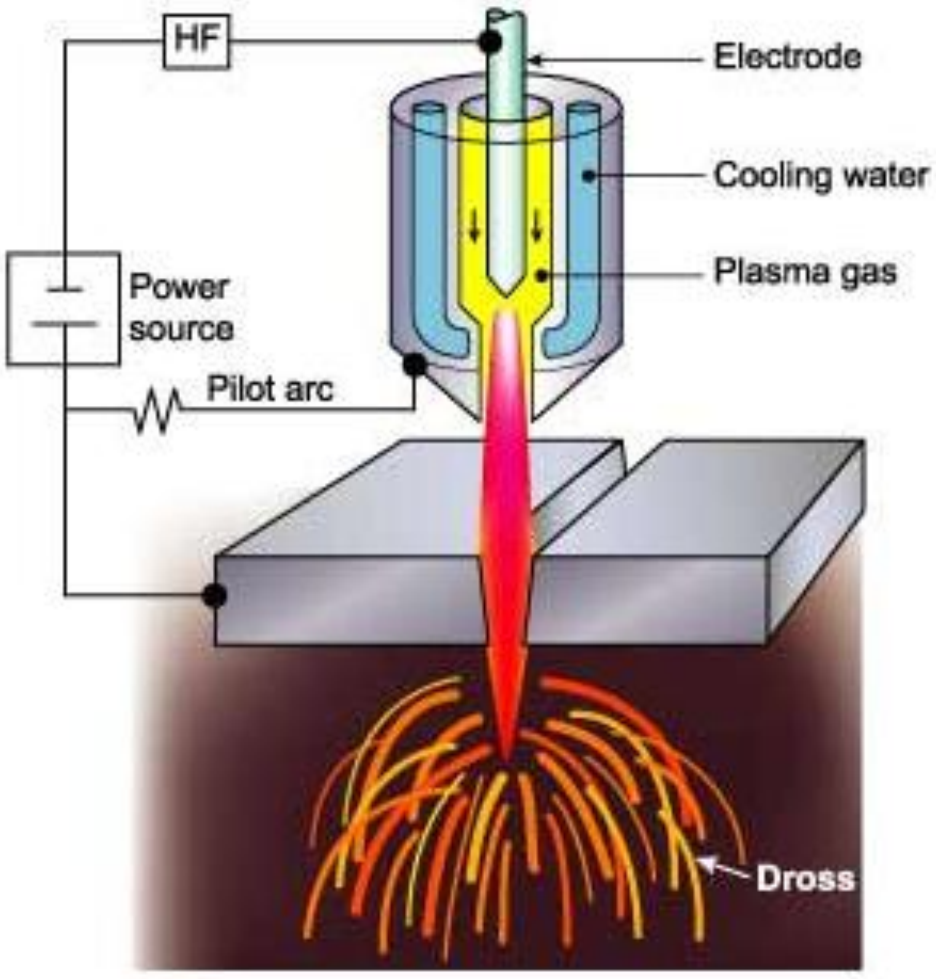
What is Plasma?

- Plasma is one of the four fundamental states of matter, the others being solid, liquid, and gas.
- Plasma is a state of matter, a gas exhibits several unusual properties such as becoming both electrically conductive and responsive to magnetism. This behaviour of plasma is unique enough for it to be considered a fourth state of maller along with solids, liquids and regular gases.



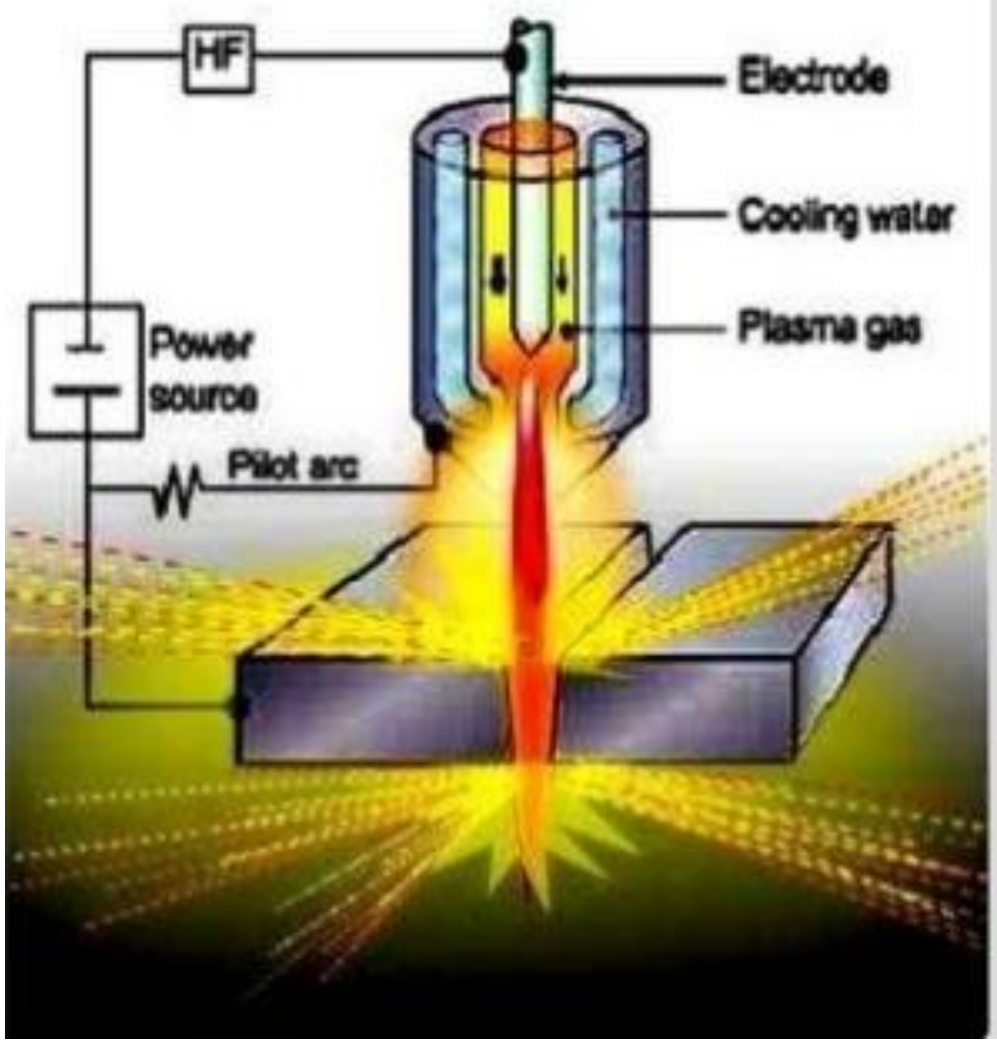
Plasma

- This change takes place when gases are heated to very high temperature
- The number of collisions between the atoms, either elastic or inelastic increases.
- The gas ionizes ,so that a portion of atoms are stripped off from outer electrons
- The electrons thus produced, in turn colloids with atoms, so that there thermal kinetic energy increases, and a light is emitted from them ,thus producing more number of atoms and electrons.

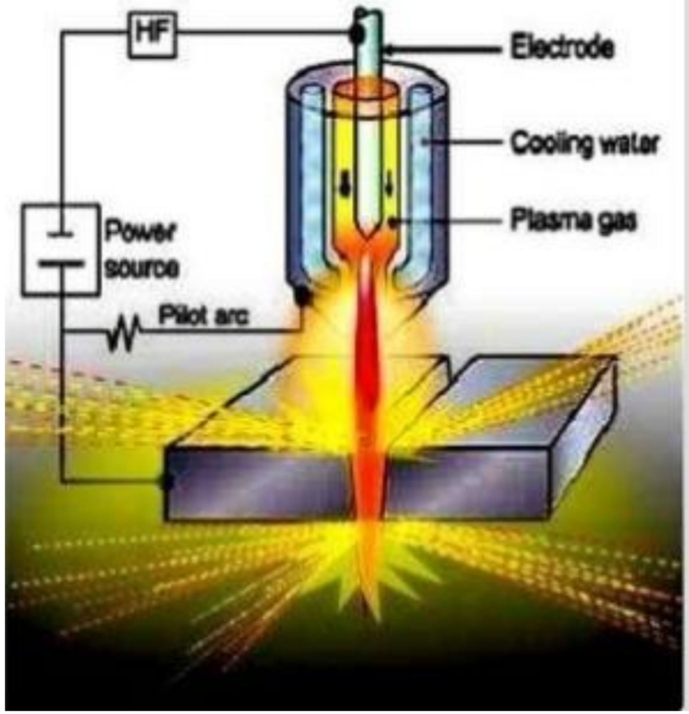


Introduction to Plasma Arc Machining (PAM)

- Plasma are initially employed to cut metals that are difficult to machine by conventional methods.
- Later, plasma arc has been successfully used for spraying, surfacing & welding metals like aluminium, stainless steel, titanium, brass and copper though other conductive metals may be cut as well.
- Plasma cutting is a process that cuts through electrically conductive materials by means of an accelerated jet of hot plasma.

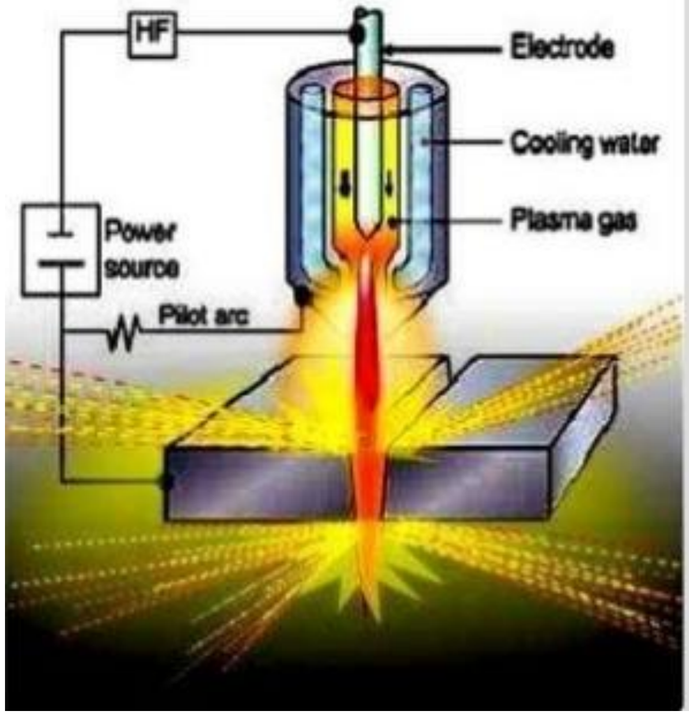


Principle of Plasma Arc Machining (PAM)



- Plasma arc machining or Plasma are cutting is a thermal machining process that is primarily used for cutting thick sections of electrically conductive materials.
- The principle of the process is based on utilizing a high-temperature plasma, which is generated by heating gases to elevated temperatures (to a few thousand degrees).
- The plasma in this state is composed of positive ions, neutral atoms, and free electrons that have become disassociated from the main gas atoms. The temperature of the plasma can be as high as 30,000°C, which means that, it can be utilized to melt and cut rapidly any type of material.

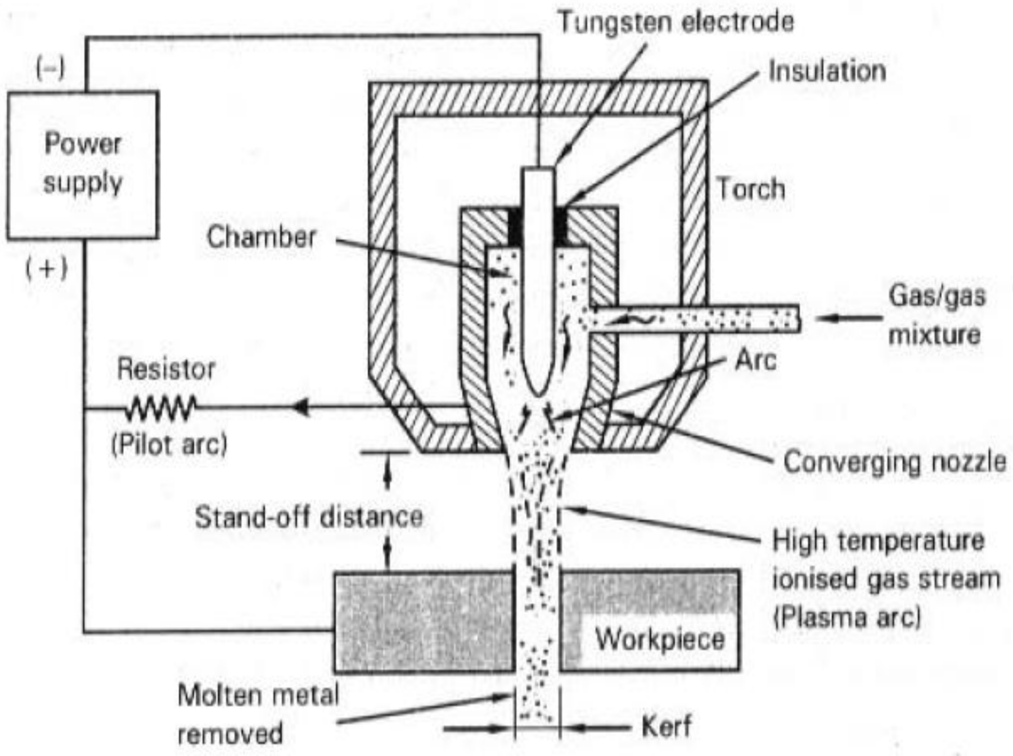
Generation of Plasma



- The method of heating the gases by first ionizing them is one of the most popular method of generating hot plasma.
- First of all the gases are heated to very high temperature of about 16000°C so as to generate plasma. This can be achieved by applying a suitable electric field across the gas column.
- The gases are then heated by an applied electric field. An igniter supplies the initial electrons ,which accelerated before colliding & ionizing.
- The free electrons get accelerated & causes ionization & heating of gases.
- This process continues till the steady state is obtained. The actual heating takes place when atoms recombines into molecules.

Generation of Plasma

- When a neutral gas /gas mixture is forced into the plasma chamber and when sufficient electric energy is supplied to the gas, the individual gas molecules become charged.
- The electric field permits acceleration of electrons of the arc within the gaseous environment due to the small masses of gas molecules.
- The high velocity electrons of the arc collide with the gas molecules producing dissociation of diatomic molecules or atoms into ions and electrons (ionization), resulting in a substantial increase in the conductivity of the gas.



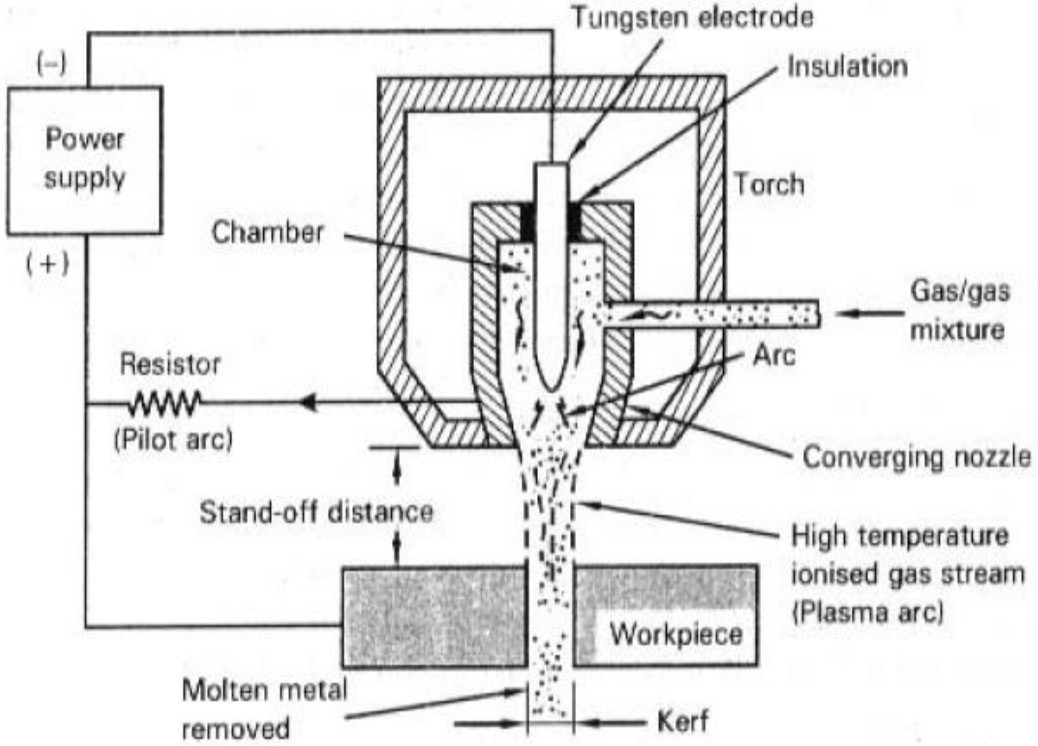
Generation of Plasma

Ionization

- Ionization is the process by which an atom or a molecule acquires a negative or positive charge by gaining or losing electrons to form ions, often in conjunction with other chemical changes.
- For example, when we supply heat energy to water, it vaporizes and separates into two gases, hydrogen and oxygen, in the form of steam. In the same manner, when we supply more energy to a gas, its characteristics are modified substantially in terms of temperature and electrical characteristics. This process is called ionization, the creation of free electrons and ions among the gas atoms. When this happens, the gas, which has now become a plasma, is electrically conductive because free electrons are available to carry current.

Generation of Plasma

- Further, an increase in temperature takes place when the ions and free electrons recombine into atoms or when the atoms recombine into molecules as these are exothermic processes.
- A high temperature plasma is generated, which is forced through the nozzle in the form of a jet.
- The maximum velocity of the jet is around 550 m/sec and the temperature is as high as 28,000°C.
- The arc is maintained stable, so that it heats the flowing gas and maintains it in the plasma state.



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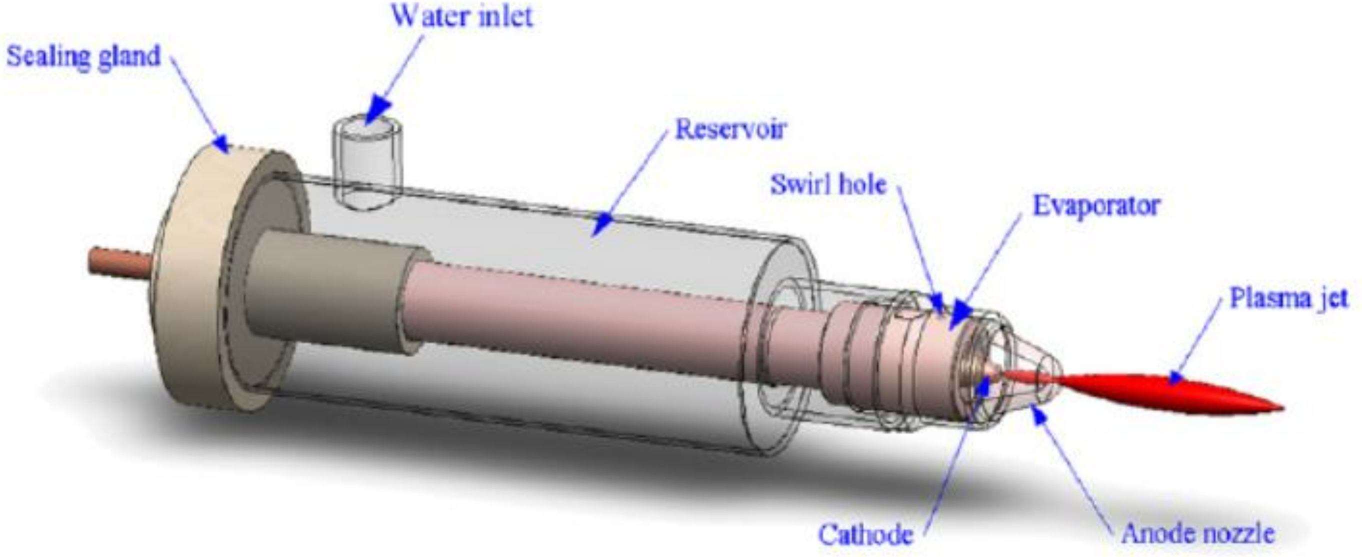
Equipment of Plasma Arc Machining (PAM)

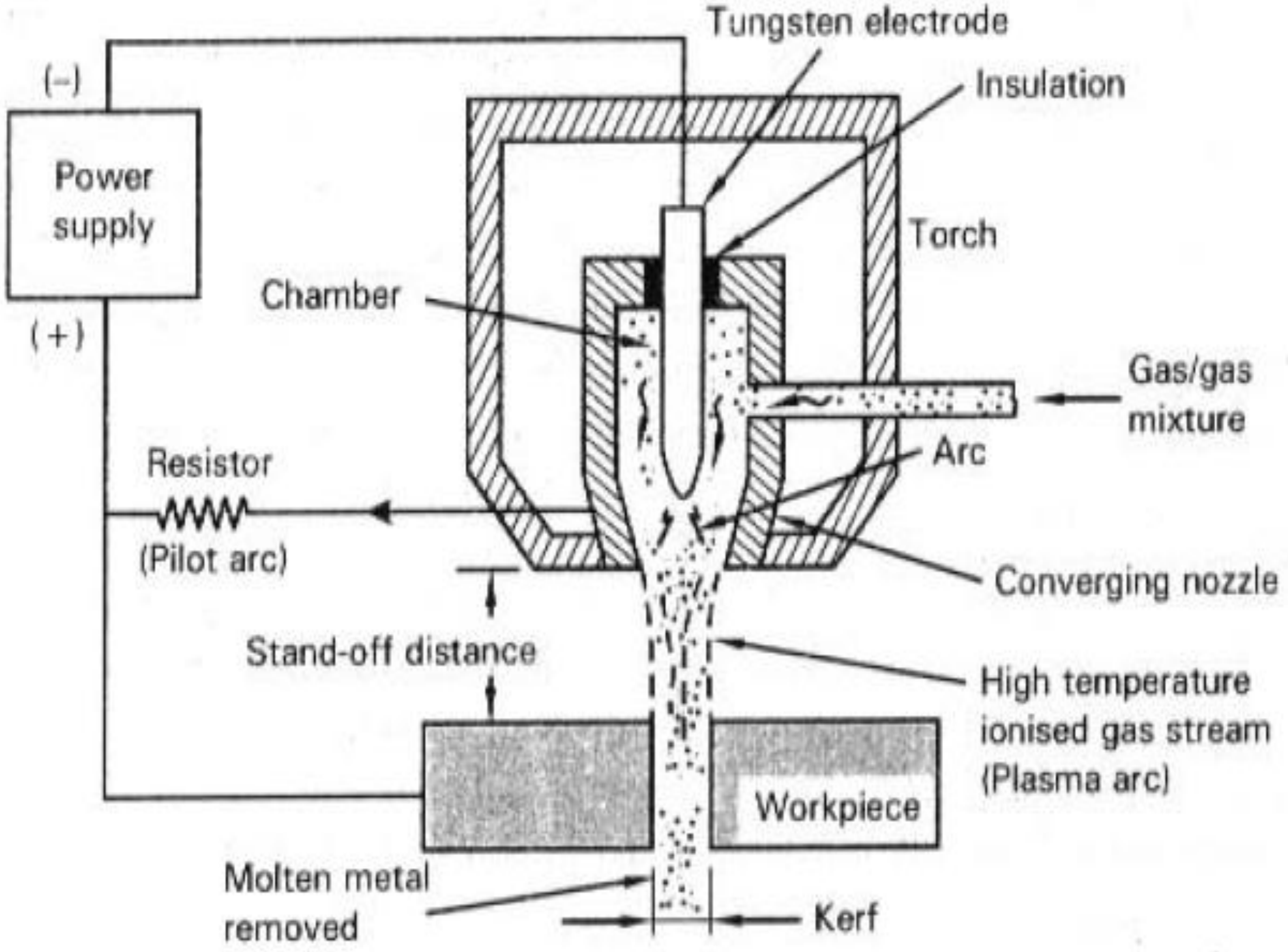
The equipment consists of a power supply, gas supply unit, cooling water system, control elements, and a plasma torch. Of all the parts that make up a system, the plasma torch is the most critical to successful operation. The various parts of the plasma equipment are

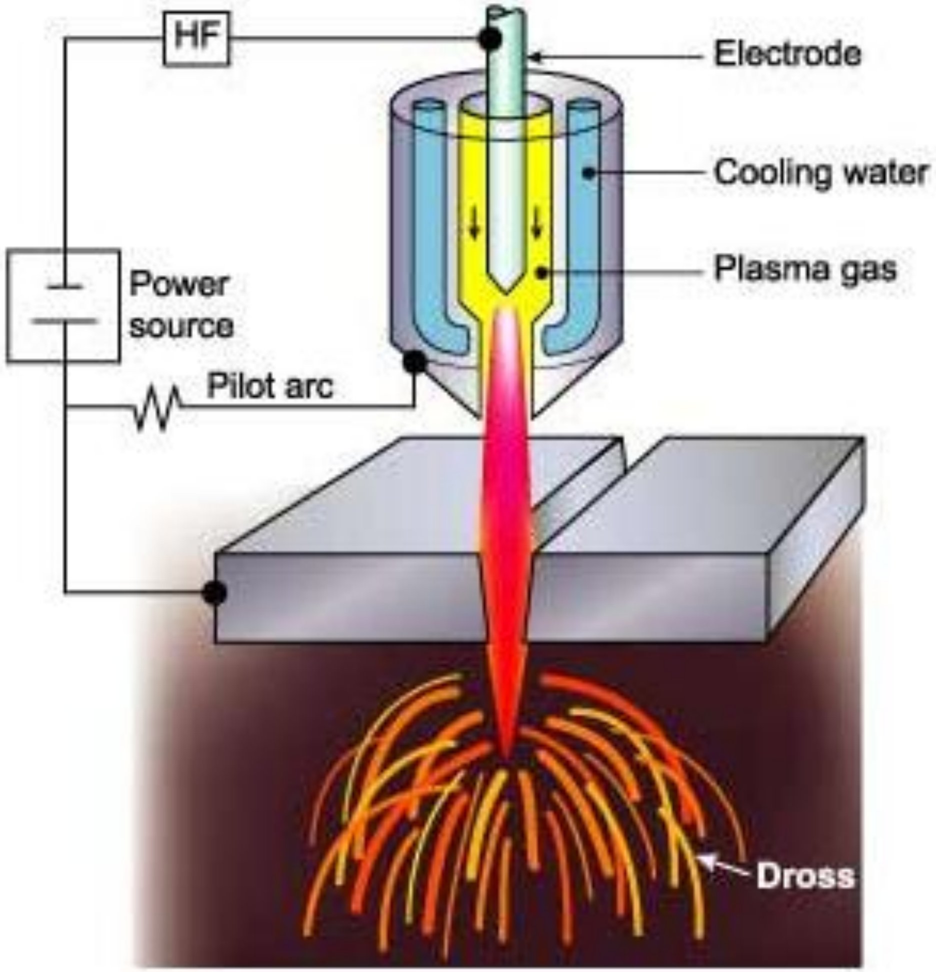
a) Plasma torch

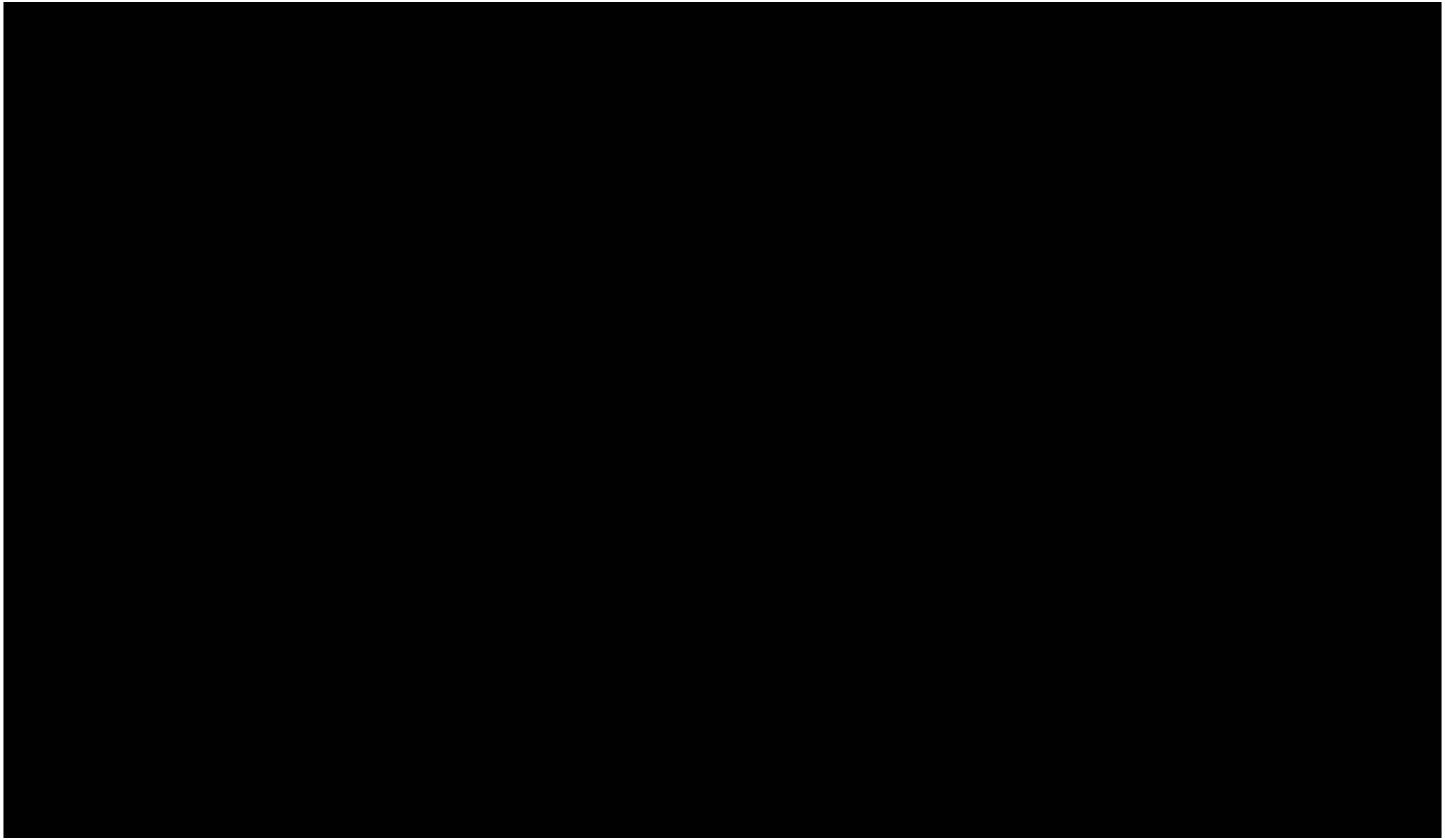
b) Gas supply and cooling water system



Equipment of Plasma Arc Machining (PAM)



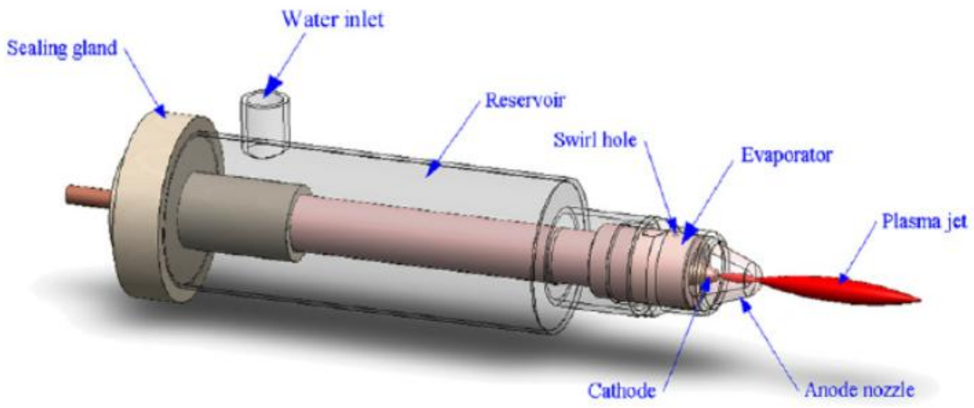




Equipment of Plasma Arc Machining (PAM)

a) Plasma torch

- A plasma torch, also known as plasma gun, or plasma cutter is a device in which a flowing gas is passed through an electric arc, producing a high-velocity jet of high-temperature ionized gas called plasma.

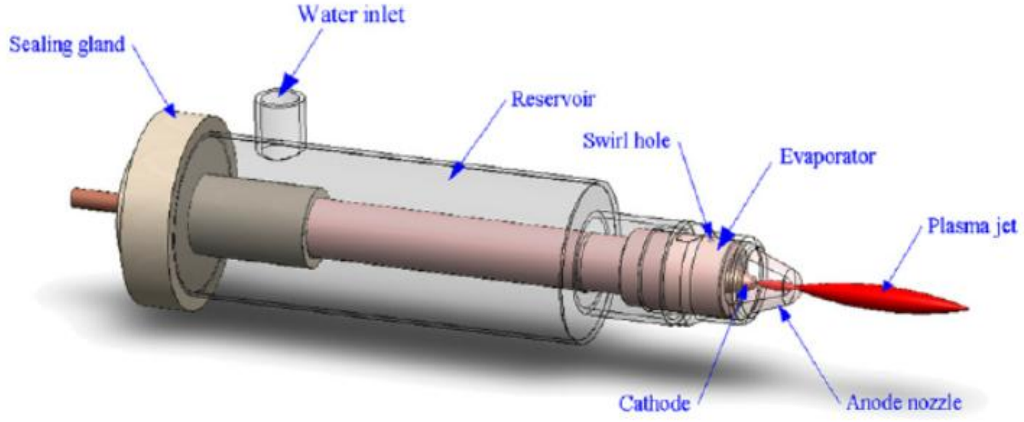


- The torch carries a 2% thoriated tungsten electrode connected to the negative terminal of a DC power supply. The tungsten electrode thus acts as a cathode in the circuit of the equipment.
- A converging nozzle with a suitable orifice encloses the tungsten electrode. The nozzle is connected to the positive terminal of the power supply through a suitable resistor to limit the current through the nozzle to about 50 Amp.
- The workpiece metal to be machined is then connected directly to the positive terminal of the power supply.

Equipment of Plasma Arc Machining (PAM)

b) Gas supply and cooling water system

- On one side of the torch is provided a passage for the supply of gas into the chamber. The type of gas used depends on the type of workpiece material being machined.
- A provision for circulating the water around the torch is provided in order to cool the electrode and the nozzle during the operation.
- Table shows the gas or gas mixture used for different types of workpiece materials.



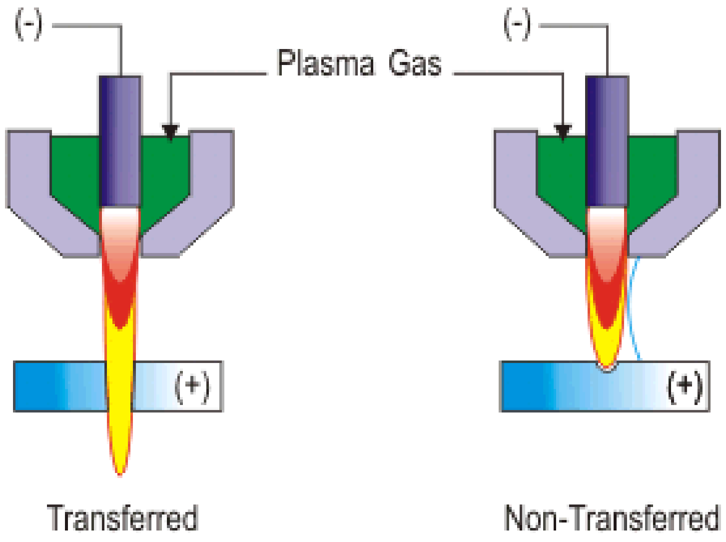
Sl. No.	Material to be cut	Gas / Gas mixture to be used
1.	Aluminum and Magnesium	Nitrogen, nitrogen-hydrogen mixture, argon-hydrogen mixture.
2.	Stainless steel and non-ferrous metals	Nitrogen-hydrogen mixture, argon-hydrogen mixture.
3.	Carbon and alloy steels, Cast iron	Nitrogen-hydrogen mixture and compressed air.

Modes of Operation of DC Torch

- Plasma is generated in Plasma Torches by means of Direct Current (D.C.), Alternating Current (A.C.), Radio-Frequency (RF) and other discharges.
- However DC torches are the most commonly used due to less flicker (light) generation and noise, better control of process, low electrode consumption, and low power consumption.
- In a DC torch, there are two modes of electrical connections that can be used.

  -transferred arc mode,

  -non-transferred arc mode.



Modes of Operation of DC Torch

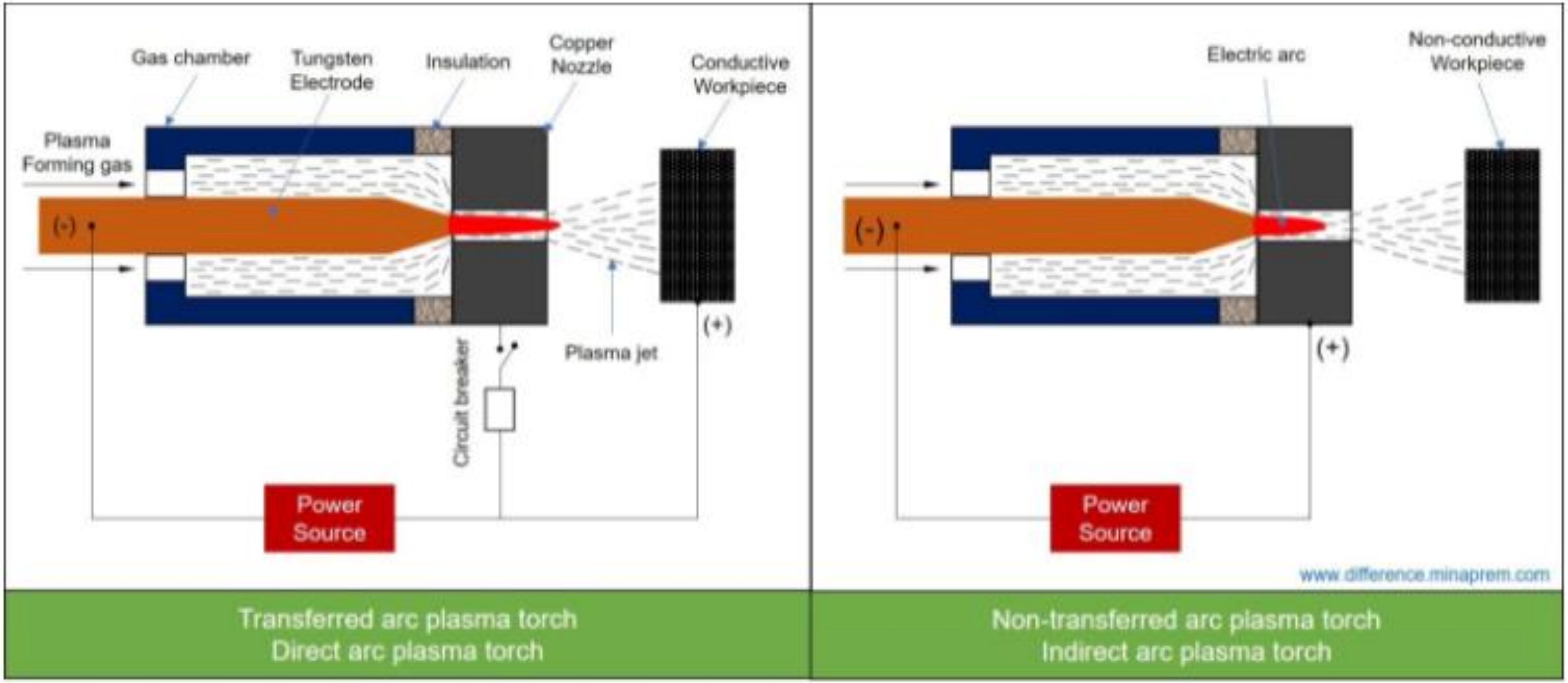
01

Non Transferred Arc Torch

02

Transferred Arc Torch

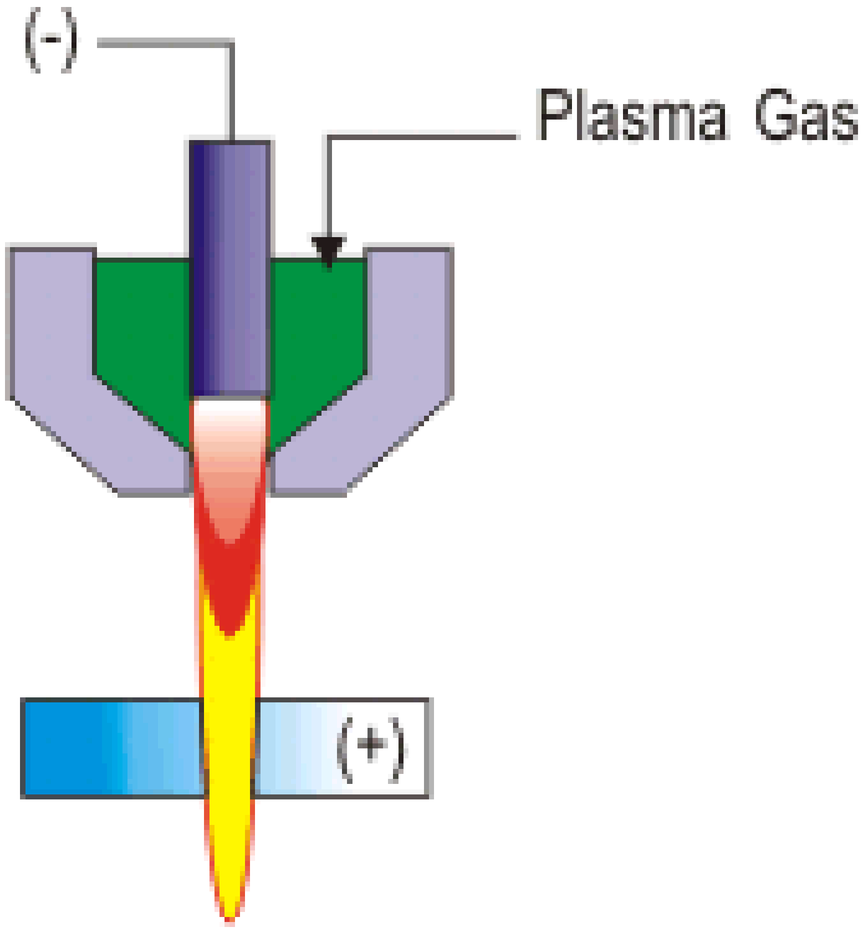
Modes of Operation of DC Torch



Modes of Operation of DC Torch

1. Transferred arc mode

- When the electrode is connected directly to the negative (cathode) of the DC source, while the nozzle is connected to the positive (anode) side of the supply through a suitable resistor.
- A pilot arc is formed within the body of the torch between the cathode electrode and the anode nozzle. The plasma thus generated with this arrangement is said to be operated in the transferred arc mode.
- Majority of the heat energy can be transferred to the workpiece material and hence metal can be removed at a faster rate. The electro-thermal efficiency is in the range of 85 to 90% and hence used for performing cutting, welding and hard surfacing of metals.

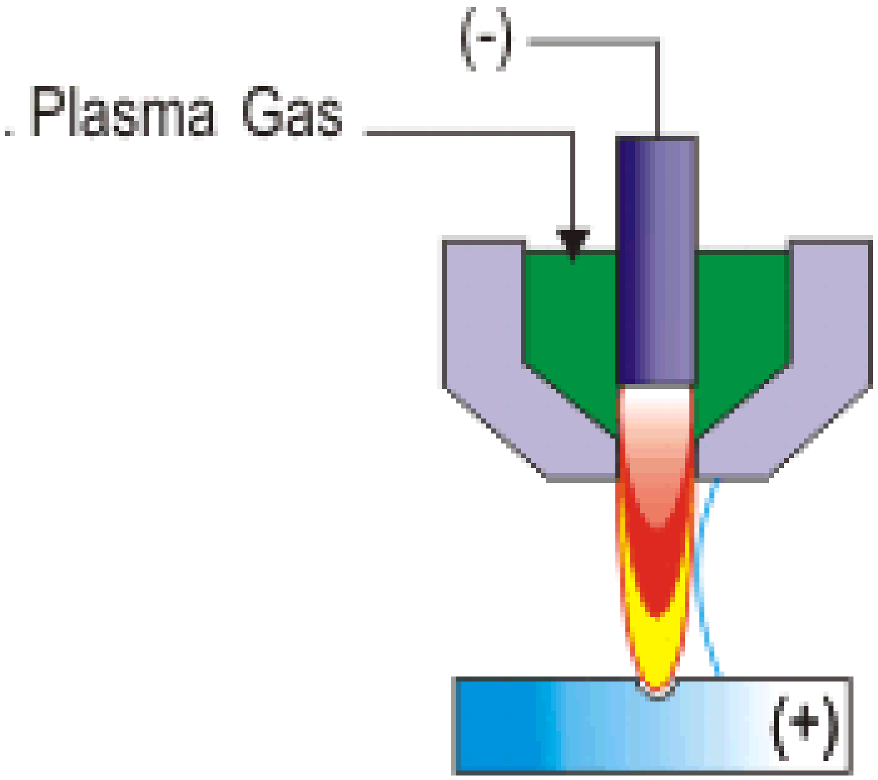


Transferred

Modes of Operation of DC Torch

2. Non Transferred arc mode

- When the DC power source is connected directly across the cathode electrode and the anode nozzle as shown in figure, the plasma generated is said to be operated in the non-transferred arc mode.
- This arrangement eliminates the necessity to have the work material as a part of the electrical system. With such an arrangement, large part of the heat generated at the anode (nozzle) is extracted by the cooling water circulated around it and hence the heat is wastefully lost (not effectively used).
- The plasma is in the form of a flame with electro-thermal efficiency being around 65%. The plasma generated by this method is used for spraying, ceramic working and chemical synthesis.



Non-Transferred

Transferred Arc Plasma Torch	Non-transferred Arc Plasma Torch
The electric arc is constituted between an electrode and the workpiece. However, an auxiliary arc is established between the electrode and nozzle at the beginning of the work for a very short period.	The electric arc is constituted between an electrode and the nozzle, and the same arc is continued for the entire operation.
Here the workpiece is made anode (positive terminal of DC power source), whereas the nozzle is kept electrically neutral. Cathode is always a copper electrode.	Here the workpiece is kept electrically neutral, whereas nozzle is made anode. As usual, cathode is always a copper electrode.
Direct arc plasma torch can be applied to electrically conductive workpieces only.	Indirect arc plasma torch can be applied to every workpiece regardless of electrical conductivity. However, it is preferred for non-conducting materials.
Direct arc has relatively higher electro-thermal efficiency (85 – 95%).	Indirect arc has comparatively low electro-thermal efficiency (65 – 75%).
Direct arc is overwhelmingly used for machining (or cutting), welding, hardfacing, remelting, and spraying.	Indirect arc is preferred for flame spraying, spheroidizing heat treatment, ore processing, etc.
Transferred arc plasma torch is also known as "Direct Arc Plasma Torch" because the arc is maintained directly between the electrode and workpiece.	Non-transferred arc plasma torch is also known as "Indirect Arc Plasma Torch" because the arc is not maintained between the electrode and workpiece though the workpiece receives the heat.

PLASMA TORCH DESIGN

The plasma torch is designed carefully so that various gases, torch coolant, water (if applicable), and electrical current can flow through the torch simultaneously without adversely affecting one another.

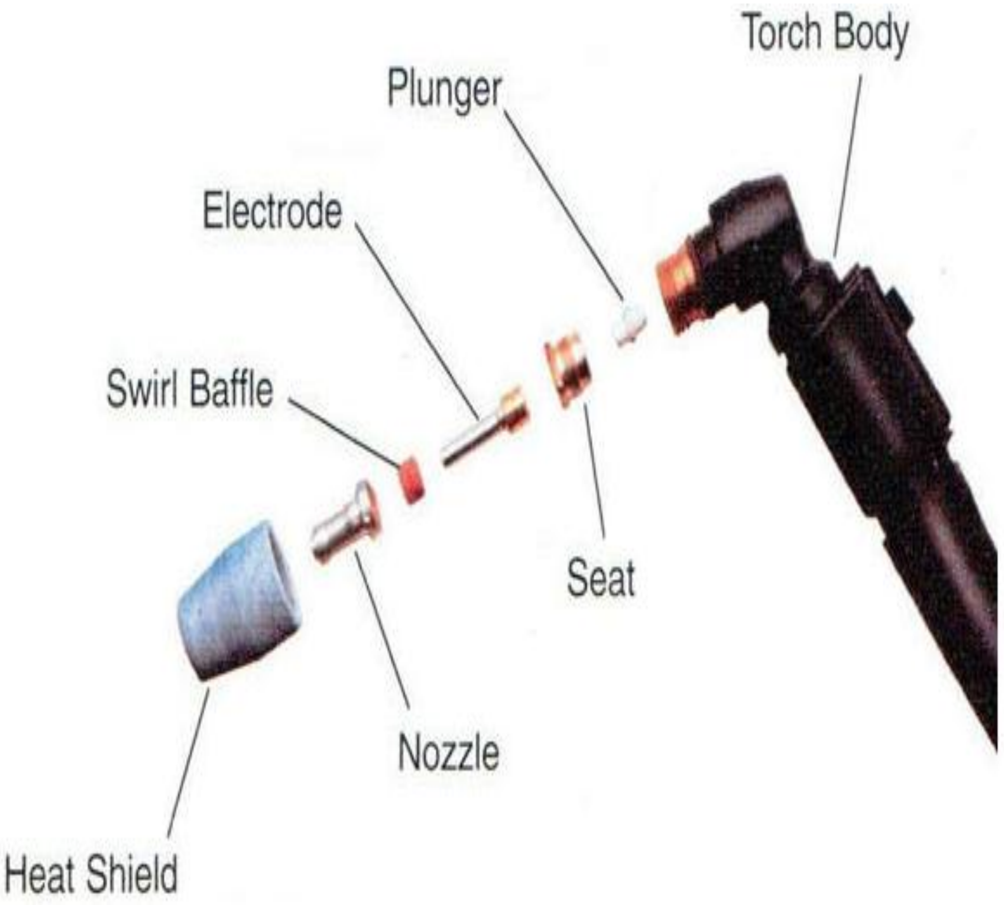
Factors to be considered while designing the Plasma Torch are as follows :

- Nozzle Design
- Electrode
- Plasma Gas
- Insulation

PLASMA TORCH DESIGN

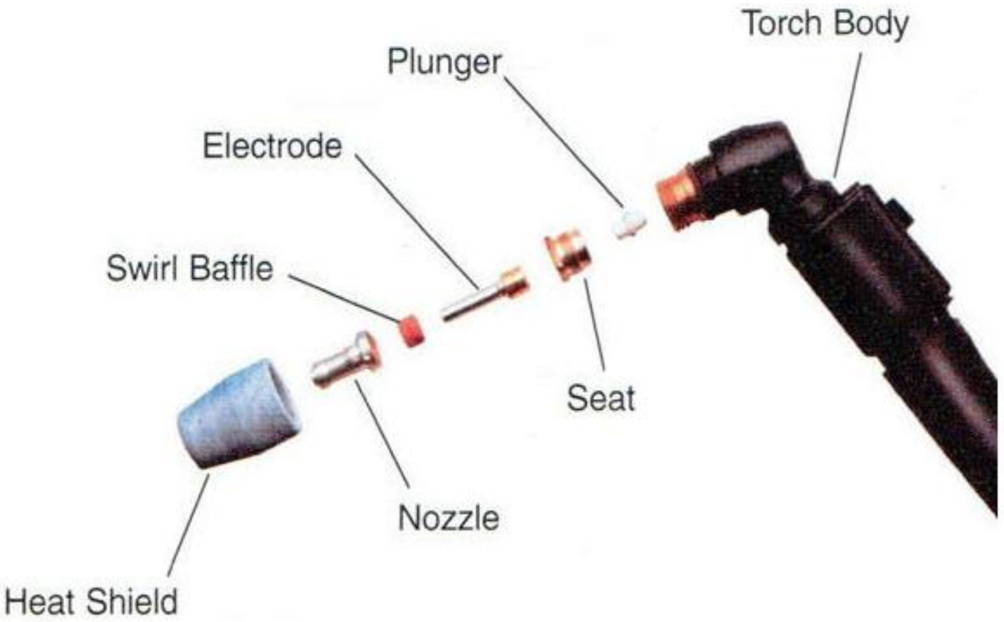
1. Nozzle Design

- The nozzle focuses the stream of plasma to produce the desired cut, and hence its design is very important for efficient machining.
- The length of the nozzle bore is directly related to the quality of cut achieved.
- A long bore generally yields a high-density arc and superior cut
- A short bore generally yields relatively poor cut quality but extended life.
- A large orifice length to diameter ratio helps in stabilizing laminar mode of flow.



PLASMA TORCH DESIGN

2. Electrode



- During the course of operation of the plasma torch, the cathode electrode is heated by the current passing through it.
- Cathode heating is a function of electrode diameter and the current passing through it. Excessive heating may cause melting of the electrode
- Cooling must be optimized for minimum melting/erosion without cracking the cathode material. While operating at larger arc voltages, it is preferable to increase the angle of taper at the cathode tip.
- The alignment of the electrode and nozzle is critical to obtaining good cut quality.
- Any misalignment would lead to undesirable arcing on the sides resulting in non-uniform erosion on one side of the electrode.

PLASMA TORCH DESIGN

3. Plasma Gas

- Plasma torch operation is highly dependent on the type of gases being used.
- Different gases have different specific heats, thermal conductivities, radical production, and power requirements.
- For example, torches designed to run on argon gas: an electrically conductive monatomic gas, would be hard-pressed and subject to thermal damage if they were required to run diatomic gases which require much more power.
- Therefore, while designing a plasma torch, the feedstock with which the torch will operate is an important consideration.

PLASMA TORCH DESIGN

4. Insulation

- Some portions of the positive and negative sections of the torch must be electrically insulated due to high frequency voltage used for ignition.
- The insulator portion must not be nearer to the arc zone in order to avoid any damage to the insulator by radiation or convection heat transfer.

Process Parameters of PAM (variables)

1. Torch-workpiece distance (stand-off) and current
2. Gas Flow Rate
3. Cutting Speed

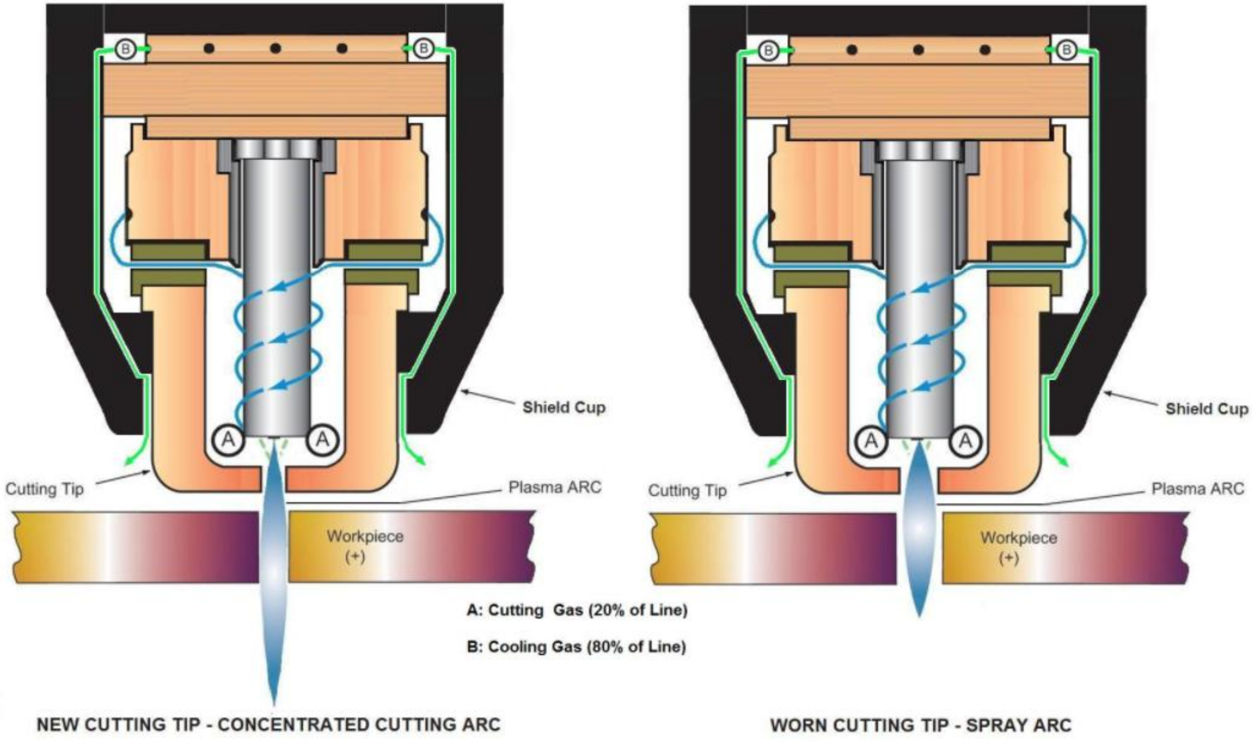
Process Parameters of ECM (variables)

1. Torch-workpiece distance (stand-off) and current

- Stand-off distance and current vary for different materials and with different thickness.
- With an increase in thickness of a particular workpiece material, the current and torchwork distance must also be increased.

Sl. No.	Material	Thickness *(mm)*	Torch-work distance *(mm)*	Current *(A)*
1.	Titanium	13	6	400
		25	10	550
2.	Copper	13	6	400
	Copper / Nickel	25	10	550
3.	Cast iron	16	6	400

- As the stand-off distance increases, the arc diverges and spreads over a wide area leading to low thermal intensity of the plasma arc.
- On the other hand, close stand-off distance can promote arcing and hence, the stand-off distance needs to be considered appropriately based on the work metal thickness.



Process Parameters of PAM (variables)

2. Gas flow rate

- The thicker the workpiece material, the greater should be the gas flow rate. However thick work materials require increased current.
- The gas flow must be set according to the current level and also the nozzle bore diameter. If the gas flow is too low for the current level, or the current level is 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.
- The gas flow rates may range between 0.4-5.6 m/hr.

Process Parameters of PAM (variables)

3. Cutting speed

- If the speed is too high, then the upper edge of the contact face comes closer to the plasma jet and receives excessive amount of heat resulting in greater metal removal rate. A kerf is produced, being very wide on the top and narrow downwards, similar to a V-shaped cross-section.
- The surface finish is also not satisfactory with high speeds. The optimum speed is achieved by advancing the torch heat at the rate at which the distribution of the heat flow from the plasma into the work material is almost uniform throughout the thickness of the material. Under such conditions, perpendicular edges are obtained, i.e., the kerf is almost as wide at the top as at the bottom.

SAFETY PRECAUTIONS in PAM

The safety precautions that need to be considered in plasma arc machining are as follows

1. The plasma flame emits ultraviolet and infrared radiations, which are harmful to human eyes and skin. Safety eye glasses or hand shields, asbestos gloves, and heat resistant clothes must be worn during the plasma operation.
2. It is necessary to carry out plasma operations in a ventilated room in order to avoid inhaling of fumes and gases emitted during the plasma generation. Gases, particularly oxides of nitrogen poses significant hazard to human operators. If ventilation is poor, air supplied respirators (masks) must be used.
3. Gas cylinders and their pressures must be monitored regularly for safety working conditions. Also electrical cable connections, power source supply, groundings, gas leaks, etc., must be checked suitably prior to operation
4. Plasma machining produces high levels of noise, and hence ear muffs or plugs must be worn

Advantages of PAM

- Precise deburring at the defined points .
- Faster than conventional deburring
- Suitable for material of any hardness
- No forming of secondary burrs
- Neither thermal nor mechanical stresses on the components.
- Suitable for mass production.

Limitations of PAM

- Limited to conductive work materials.
- Burrs should be of consistent shape and size.
- Not suitable for small productions.
- High equipment cost.
- Post cleaning of work and equipment parts is necessary in order to avoid corrosion effects of the electrolytes used.

Applications of PAM

- Plasma arc process for cutting aluminum and other nonferrous materials was first introduced in 1955.
- Due to the remarkable results, the process has now been widely accepted by industries for varied applications.
- The major areas of industrial production where plasma jets have successfully been employed are:
  - Welding of material like titanium, stainless steel, etc. which are other-wise difficult to weld.
  - Plasma arc surfacing.
  - Plasma arc spraying.
  - Sufficient literature on plasma arc welding is available but little information regarding plasma arc surfacing and spraying exist.