ADVANCED MANUFACTURING CAD & CAM

CHAPTER 1-ADVANCED MACHINING

Abstract

This will give you a brief idea about the most used machining processes of the century.

This handout will cover the following types of advanced mechanical machining processes.

The processes are as follows

1. Abrasive Jet Machining
2. Electrochemical Machining
3. Electro-discharge Machining
4. Electron Beam Machining
5. Laser Beam Machining
6. Plasma Arc Machining

ABRASIVE JET MACHINING

Principle of Operation

The fundamental principle of Abrasive jet machining involves the use of a high-speed stream of abrasive particles carried by a high-pressure gas or air on the work surface through a nozzle.

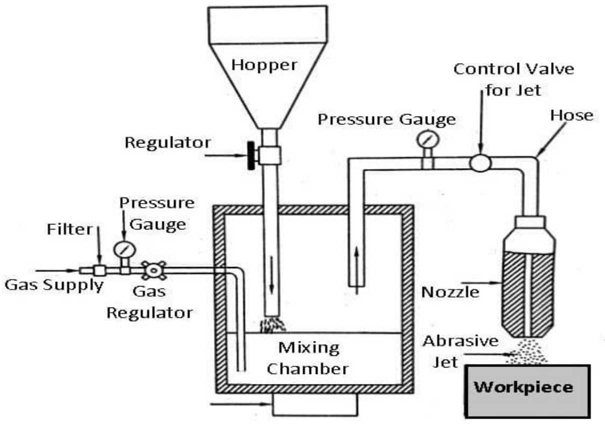
The metal is removed due to erosion caused by the abrasive particles impacting the work surface at high speed. With repeated impacts, small bits of material get loosened and a fresh surface is exposed to the jet.

This process is mainly employed for such machining works which are otherwise difficult, such as thin sections of hard metals and alloys, cutting of material which is sensitive of heat damage, producing intricate holes, deburring, etching, polishing etc.

Construction & Working

Parts of Abrasive Jet machine

The figure shows a schematic diagram of the abrasive jet machine.



Gas Supply

The filtered gas, supplied under a pressure of 2 to 8 kgf/cm^2 to the mixing chamber containing the abrasive powder and vibrating at 50 Hz entrains the abrasive particles and is then passed into a connecting hose. This abrasive and gas mixture emerges from a small nozzle mounted on a fixture at a high velocity ranging from 150 to 300 m/min.

Abrasive

Abrasive powder feed rate is controlled by the amplitude of vibration of the mixing chamber. The gas flow and pressure is controlled by a pressure regulator. To control the size and shape of the cut either the work piece or the nozzle is moved by cams, pantographs or other suitable mechanisms.

The abrasives generally used are silicon carbide, aluminum oxide, glass powder or specially prepared sodium bicarbonate. The common particle sizes vary from 10 microns to 50 microns. Smaller sizes are used for good surface finish and precision work. While larger sizes are used for rapid removal rate.

In addition to the above abrasives, dolomite (calcium magnesium carbonate) of 200 grit size is found suitable for light cleaning and etching. Glass beads of diameter 0.30 to 0.60 mm are used for light polishing and deburring.

Nozzle

Nozzles have a great degree of abrasion wear, they are made of hard materials such as tungsten carbide or synthetic sapphire to reduce the wear rate. Nozzles made of tungsten carbide have an average life of 8 to 12 hours. While nozzles of sapphire last for about 300 hours of operation when used with 27-micron abrasive powder. The gases used are nitrogen, carbon dioxide or clean air.

Work piece

The metal removal rate depends upon the diameter of the nozzle, the composition of the abrasive gas mixture, the hardness of abrasive particles and that of work material, particle size, the velocity of jet and distance of the work piece from the jet. A typical material removal rate for abrasive jet machining is 16 mm/min in cutting glass.

Working

A typical set-up for abrasive jet machining is shown in the figure. The abrasive particles are held in a suitable holding device, like a tank and fed into the mixing chamber**.** A regulator is incorporated in the line to control the flow of abrasive particles compressed air or high-pressure gas is supplied to the mixing chamber through a pipeline.

This pipeline carries a pressure gauge and a regulator to control the gas flow and its pressure. The mixing chamber, carrying the abrasive particles is vibrated and the amplitude of these vibrations controls the flow of abrasive particles.

These particles mix in the gas stream, travel further through a hose and finally pass through the nozzle at a considerably high speed. This outgoing high-speed stream of the mixture of gas and abrasive particles is known as abrasive jet.

Advantages:

Ability to cut fragile, brittle or heat sensitive material without damage

Ability to cut intricate hole shapes in materials of any hardness.

Virtually no heat is generated in the w/p.

Low capital cost.

Dis-advantages of AJM:

Slow MRR.

Stray cutting and hence accuracy is not good.

Embedding of abrasive in the w/p.

Abrasive power cant be reused.

AJM requires some type of dust collecting system.

Application of AJM:

Cleaning

Cutting fine lines

Machining semiconductors

Cutting and etching quartz, sapphire, mica

Drilling and cutting thin sections of hardened metal

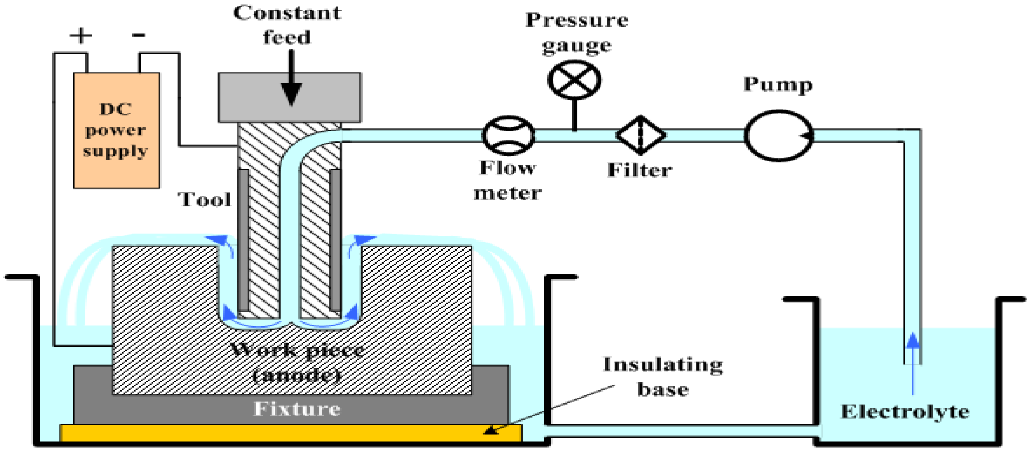
Removing plating, anodic or thermal oxide coatings

ELECTROCHEMICAL MACHINING

CONSTRUCTION AND WORKING PRINCIPLE OF ECM

Electro-chemical machining process is based on the fundamental laws of electrolysis, which states that the amount of material deposited or dissolved is directly proportional to the current density multiplied by the time.

High density D.C of that is from 5 to 24 volt but 500 to 25000Amps currents is passed through an electrolyte solution that fills up the gap between the w/p(anode) and the shaped tool(cathode). The electro-chemical reaction depletes the metals from the w/p.



From figure work piece must be a conductor of electricity is placed in the tank on machine table and connected to positive terminal of D.C supply. The work piece made anode. The tool electrode shaped to form required cavity in w/p is mounted on the tool holder connected to negative terminal of the supply. An electrolyte flows through the gap of 0.0254 to 0.76mm between the tool and the w/p and then pumped back to the working zone.

The action of the current flowing through the electrolyte is to dissolve the metal from the w/p and the flowing electrolyte carry the removed metal with it. The form of tool will reproduce on the w/p.

The elements of ECM are

Electrode

Electrolyte

Filter and settling tanks

Power supply

Work piece

Electrodes:

Electrodes used are generally copper, copper alloys, type 316 stainless steel and titanium

The tool electrodes are insulated except the cutting tip.

The tool surfaces should be polished to get good surface finish.

Electrolyte:

Generally electrolytes that are used are water solution of NaCl, KCl, $NaNO_3$, NaOH

Electrolytes should not be too corrosive and must be filtered continuously.

The electrolytes is circulated under pressure of 50 to 150 psi.

The parts of ECM is generally made of Stainless steel and provided with corrosion resistant paint

Filters or settling tank

Filter and settling tanks are used to clean electrolyte.

Centrifuges are used when larger ECM is used.

Power Supply:

5V-24V DC

500amp to 25000amp of current

Work piece:

It must be a good conductor of electricity.

Advantages of ECM:

- There is no significant tool wear.
- Metal removal rate is high.
- Difficult shapes can be machined easily.
- The machined surfaces are stress free
- The surface finish can be maintained at 0.1 to 2.5mm.
- Several operations such as milling, grinding, deburring, polishing can be eliminated.
- Complex shapes can be easily produced.

Disadvantages of ECM:

- The tools are more difficult to design.
- The initial cost is high.
- The power consumption is high.
- The electrolyte is corrosive to equipment, work-piece and fixtures.
- Fixtures must be used to hold the work piece.

Application of ECM:

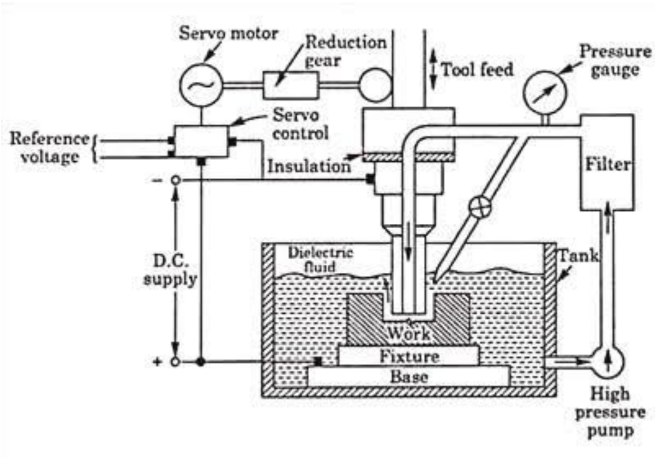
- Used for high strength high hardness material.
- Jet engine blade cooling holes.
- Turbine wheel with integral blades.
- Used high temperature alloy forgings.
- Honey comb cores, assemblies and other fragile parts.

ELECTRICAL DISCHARGE MACHINING

Construction and Working Principle:

EDM composed of

- A **POWER SUPPLY** to provide direct current (0.5-400amp) and a method to control voltage (40-300V D.C) and frequency.
- The **TOOL HEAD** holding the electrode made up of copper, tungsten and graphite alloy. Electrode can be compared with the cutting tool of conventional machining. The shape of the electrode is same as that of the part desired except the allowance is made for side clearance and over cut.
- A **SERVOMECHANISM** to accurately control the movement of the electrode to maintain the correct distance between it and work-piece as the machining process go. It also maintains a thin gap of 0.025mm between the electrode and work.
- A **COOLANT/DIELECTRIC FLUID** is usually a light mineral oil that forms a dielectric barrier between the electrode and work at the arc gap. The electrode and work both are submerged in dielectric fluid.



Working:

When the voltage across the gap reaches a point sufficient to cause the dielectric fluid to break down, and a spark occurs. The temperature around 10000^0 C and pressure many thousand times greater than the atmospheric is created, all in less than one microsecond for each spark. Each spark erodes a minute piece of metal from the work piece. But if the sparks occurs 20000 to 30000 times per second, appreciable quantity of metal is removed. The dielectric is also used to flush particles from the gap, keep the electrode and work cool, prevent fusion of the electrode with the work. A filter is used to remove the particles from the dielectric fluid.

Advantages of EDM:

- Any material regardless of hardness and strength can be machined provided it can conduct electricity.
- Any shapes that can be produced in a tool can be duplicated in the w/p.
- Since no mechanical force is required, even the most delicate materials can be machined by EDM without distortion.
- Since no mechanical force is applied by the tool, very delicate tool materials and shapes can be used to produce fine details.
- The tool and dies can be spark machined after they are hardened and hence great accuracy can be achieved.

Disadvantages of EDM:

- The w/p and tool must both conduct electricity.
- EDM is slow, whenever possible the shape or hole is roughed out before using EDM.
- Because of the intense heat, thermal distortion is a problem.

Application of EDM:

- In tool making- for press tools, extrusion dies, forging dies and molds.
- The oil retention property of the surface machined by EDM makes it suitable for finishing plain bearing and bores IC engine cylinders.
- EDM has been successfully used to drill very small diameter holes in such hardened parts as nozzle for diesel engine fuel injectors.

ELECTRON BEAM MACHINING

Electron Beam Machining is process in which high velocity electrons are concentrated in a narrow beam and then directed towards the work-piece for machining. When this high velocity electron strikes the work-piece, it melts and vaporizes the material from the work-piece.

Working Principle

In an electron beam machining, the electrons strike the work-piece with a high velocity. As the electron strikes the work-piece, the kinetic energy of the electron changes into heat energy. The heat energy so produced is used to melt and vaporize the materials from the w/p. The whole process takes place in vacuum. Vacuum environment is used to prevent the contamination and avoid collision of electrons with air molecules. If the electrons collide with the air molecules, it will lose its Kinetic energy.

Construction

The various equipment used in EBM machine are

1. Cathode

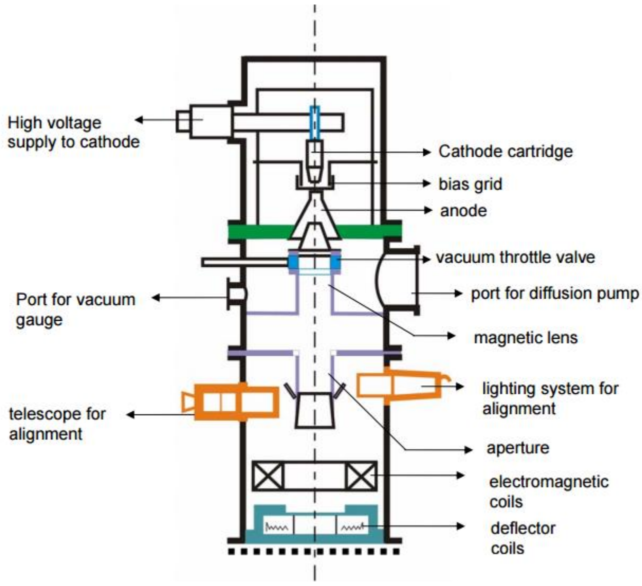
The cathode is negatively charged and it is used to produce Electrons.

2. Grid

It is present next to the cathode. Grid is a circular shaped bias grid and prevents the diversion of electrons produced by the cathode. It works as a switch and makes the electron gun to operate in pulse mode.

3. Anode

It is placed after the grid. It is positively charged. Annular anode attracts the beam of electron towards it and gradually the velocity of the electron increases. As the electron beam leave the anode section, its velocity becomes half of the velocity of light.



4. Magnetic Lenses

The magnetic lenses reduce the divergence of electron beam and shape them. It allows only convergent electrons to pass and captures the low energy divergent electrons from fringes. It improves the quality of the beam.

5. Electromagnetic Lens

It helps the Electron beam to focus on the desired spot.

6. Deflector Coils

The deflector coil carefully guides the high velocity electron beam to a desired location on the work-piece and improves the shape of the holes.

Working of Electron Beam Machining

- In EBM, first the electron is generated by the cathode and an annular biased grid does not allow the electron to diverge.
- From the annular bias grid, the electron produced by the cathode is attracted towards the anode and gradually its velocity increases. As the electron beam leaves the anode section, its velocity reaches to half of the velocity of the light.
- After that, it passes to the series of magnetic lenses. The magnetic lenses allow only convergent beam to pass through it and captures the divergent beam from the fringes. And then a high quality electron beam is made to pass through the electromagnetic lens and deflector coils.
- The electromagnetic lens focuses the electron beam to the desired spot on the work-piece. The deflector carefully guides the beam to the desired locations and improves the shape hole.

Characteristics

(i) The Electron Beam machine is operated in pulse mode and this is achieved by the biasing annular biased grid.

(ii) The beam current can be as low as 200 μA to 1 A.

(iii) The pulse duration achieved in the EBM machine is 50 μs to 15 ms.

(iv) The energy possessed by the pulse is 100 j/pulse.

(v) It utilizes voltage in the range of 150 kV to 200 kV. And this voltage is used to accelerate Electrons to about 200,000km/s.

Advantages

1. It can produce bolts of small sizes.
2. High accuracy and better surface finish.
3. Almost all types of materials can be machined.
4. Highly reactive metals such as Al and Mg can be machined easily.
5. As it does not apply any mechanical cutting forces on the work-piece, so cost of work holding and fixtures is reduced.

Disadvantages

1. High equipment cost.
2. Low metal removal rate.
3. High skilled operator is required.
4. High power consumption.
5. Not applicable to produce perfectly cylindrical deep holes.

Application

1. Electron Beam Machining is used to produce smaller size diameter holes.
2. It is used for micromachining.
3. Various industries like automobile, aerospace and marine uses this machining.

LASER BEAM MACHINING

Laser Beam Machining (LBM) is a form of machining process in which laser beam is used for the machining of metallic and non-metallic materials. In this process, a laser beam of high energy is made to strike on the work-piece, the thermal energy of the laser gets transferred to the surface of the w/p (work-piece). The heat so produced at the surface heats, melts and vaporizes the materials from the w/p. Light amplification by stimulated emission of radiation is called **LASER**.

WORKING PRINCIPLE

It works on the principle that when a high energy laser beam strikes the surface of the work-piece. The heat energy contained by the laser beam gets transferred to the surface of the w/p. This heat energy absorbed by the surface heat melts and vaporizes the material from the w/p. In this way the machining of material takes place by the use of laser beam.

In normal condition, the electrons present in atoms lies in the ground state (lowest energy level). When some source of energy is provided to the atoms in the form of radiation, the electrons of the atoms absorbs energy and excited to higher energy level. After a short duration, these electrons automatically jump back to the ground state and while doing so they emit photons of light. This emission of photons by the electrons is called **spontaneous emission**.

When the electrons in the excited state do not jumps back to the ground state by its own. This situation is called meta-stable state. When a photon is fired to the meta- stable state of atoms, this stimulates an electron at excited state and it jumps back to its ground state giving of two photons (one photon that we fired and other produced by the electron). These two photons stimulate other atoms electrons and produces more photons- a chain reactions starts and number of photon increases. This process is called stimulated emission as we are stimulating other electrons to get photons. Here we are getting two light photons from a single photon i.e. amplifying the light (increasing the light).

Hence the light beams produced by this method is called laser (light amplification by stimulated emission of radiation).

On the basis of the media used for the production of the laser it is classified as

1. **Gas Lasers:** In these types of laser, gases are used as the medium to produce lasers. The commonly used gases are He-Ne, argon and Co2.
2. **Solid State Lasers:** The media of the solid state lasers are produced by doping a rare element into a host material.

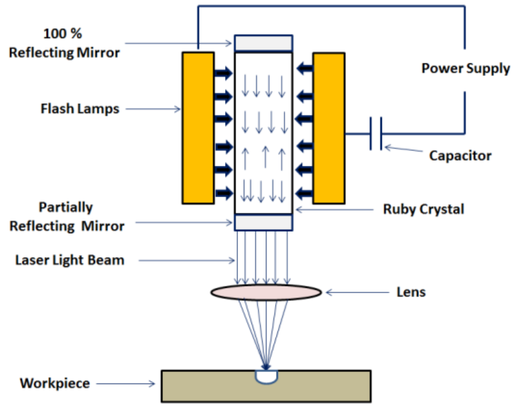
Ruby laser is an example of solid state laser in which ruby crystal is used as medium for the generation of laser beam.

The other media used in the solid state lasers are

(i) **YAG:** For yttrium aluminum garnet which a type of crystal.

(ii) **Nd:YAG** – Refers to neodymium-doped yttrium aluminum garnet crystals

CONSTRUCTION AND WORKING



The various main parts used in the laser beam machining are

1. **A pumping Medium**: A medium is needed that contains a large number of atoms. The atoms of the media are used to produce lasers.
2. **Flash Tube/Flash Lamp:** The flash tube or flash lamp is used to provide the necessary energy to the atoms to excite their electrons.
3. **Power Supply:** A high voltage power source is used to produce light in flashlight tubes.
4. **Capacitor:** Capacitor is used to operate the laser beam machine at pulse mode.
5. **Reflecting Mirror:** Two types of mirror are used, first one is 100 % reflecting and other is partially reflecting. 100 % reflecting mirror is kept at one end and partially reflecting mirror is at the other end. The laser beam comes out from that side where partially reflecting mirror is kept.

How Laser is Produced

- A high voltage power supply is applied across the flash tube. A capacitor is used to operate the flash tube at pulse mode.
- As the flash is produced by the flash tube, it emits light photons that contain energy.
- These light photons emitted by the flash tube is absorbed by the ruby crystal. The photons absorbed by the atoms of the ruby crystals excite the electrons to the high energy level and population inversion (situation when the number of exited electrons is greater than the ground state electrons) is attained.
- After short duration, these excited electrons jump back to its ground state and emits a light photon. This emission of photon is called spontaneous emission,
- The emitted photon stimulates the excited electrons and they start to return to the ground state by emitting two photons. In this way two light photons are produced by utilizing a single photon. Here the amplification (increase) of light takes place by stimulated emission of radiation.
- Concentration of the light photon increases and it forms a laser beam.
- 100 % reflecting mirror bounces back the photons into the crystal. Partially reflecting mirror reflects some of the photons back to the crystal and some of it escapes out and forms a highly concentrated laser beam. A lens is used to focus the laser beam to a desired location.

A very high energy laser beam is produced by the laser machines. This laser beam produced is focused on the work-piece to be machined.

When the laser beam strikes the surface of the w/p, the thermal energy of the laser beam is transferred to the surface of the w/p. this heats, melts, vaporizes and finally removes the material form the work-piece. In this way laser beam machining works.

Advantages

1. It can be focused to a very small diameter.
2. It produces a very high amount of energy, about 100 MW per square mm of area.
3. It is capable of producing very accurately placed holes.
4. Laser beam machining has the ability to cut or engrave almost all types of materials, when traditional machining process fails to cut or engrave any material.
5. Since there is no physical contact between the tool and work-piece. The wear and tear in this machining process is very low and hence it requires low maintenance cost
6. This machining process produces object of very high precision. And most of the object does not require additional finishing
7. It can be paired with gases that help to make cutting process more efficient. It helps to minimize the oxidation of w/p surface and keep it free from melted of vaporized materials. Produces a very high energy of about 100 MW per square mm of area.
8. It has the ability to engrave or cut almost all types of materials. But it is best suited for the brittle materials with low conductivity.

Disadvantages

1. High initial cost. This is because it requires many accessories which are important for the machining process by laser.
2. Highly trained worker is required to operate laser beam machining machine.
3. Low production rate since it is not designed for the mass production.
4. It requires a lot of energy for machining process.
5. It is not easy to produce deep cuts with the w/p that has high melting points and usually cause a taper.
6. High maintenance cost.

Application

1. The laser beam machining is mostly used in automobile, aerospace, shipbuilding, electronics, steel and medical industries for machining complex parts with precision.
2. In heavy manufacturing industries, it is used or drilling and cladding, seam and spot welding among others.
3. In light manufacturing industries, it is used for engraving and drilling other metals.
4. In the electronic industry, it is used for skiving (to join two ends) of circuits and wire stripping.
5. In medical industry, it is used for hair removal and cosmetic surgery.

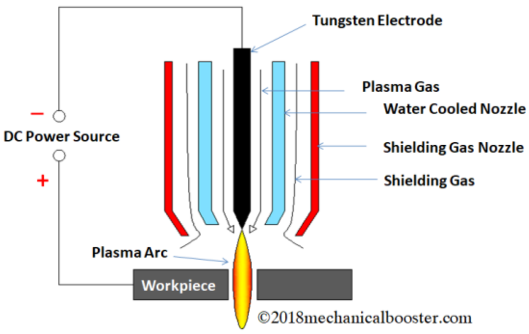
PLASMA ARC MACHINING

Introduction

When a gas or air heated at high temperatures, the number of collisions between atoms increases. When you heat the gas above 5500ºC, it partially ionizes into positive ions, negative ions and neutral ions. When you further heat the gas above 11000ºC then, it completely ionizes. Such a completely ionized gas is called Plasma. Plasma State lies in between temperatures 11,000ºC to 28,000ºC. Basically, Plasma Arc Machining (PAM) is a metal cutting process where metals are cut with plasma arc, tungsten-inert-gas arc or a torch. It is mostly used for the metals that cannot be cut by an oxyacetylene torch. In PAM, different gases are used according to different material. Different material means a work piece. For example, for aluminum nitrogen is used. In most of the cases, nitrogen and hydrogen are used. Plasma Arc Welding employs a high-velocity jet of high-temperature gas to melt and displace material in its path.

Construction & Working

Plasma arc machining consists of a Plasma gun. Plasma gun has an electrode made up of tungsten situated in the chamber. Here, this tungsten electrode is connected to the negative terminal of DC power supply. Thus, the tungsten acts as a cathode. While the positive terminal of DC power supply is connected to the nozzle. Thus, the nozzle of the plasma gun acts as an anode.



Plasma Arc Machining

As we give the power supply to the system, an electric arc develops between the tungsten electrode and an anodic nozzle. As the gas comes in contact with the plasma, there is a collision between the atoms of gas and electrons of an electric arc and as a result, we get an ionized gas. That, means we get the plasma state that we wanted for Plasma Arc machining. Now, this plasma is targeted towards the work-piece with a high velocity and the machining process starts. One thing to note down is that a high potential difference is applied in order to get the plasma state.

In the whole process, high temperature conditions are required. As hot gases come out of nozzle there are chances of overheating. In order to prevent this overheating, a water jacket is used.

Following are some of the parameters involved in PAM that you must consider are:

- Current: Up to 500A
- Voltage: 30-250V
- Cutting speed: 0.1-7.5 m/min.

- Plate thickness: Up to 200mm
- Power require: 2 to 200 KW
- Material removal rate: 150 cm^3/min
- Velocity of Plasma: 500m/sec
- Material of work-piece: As previously stated, you can use any metal as material of work-piece. For instance, aluminum and stainless steel are highly recommended for this process.

Advantages

Following are the advantages of PAM that you must know:

- In Plasma Arc Machining, hard as well as brittle metals can be easily machined.
- It can be applied to almost all types of metals.
- The best part of this process is that we get high cutting rate.
- We get a better dimensional accuracy in case of machining small cavities.
- It is a simple process to carry out and a very efficient process.
- It takes a big part in automatic repair of jet engine blades.

Disadvantages

Apart from the advantages of the Plasma Arc machining let us discuss some of the disadvantages of it:

- PAM involves various equipment but the cost of this equipment is very high.
- This entire machining process consumes a high amount of inert gases.
- Production of narrower surfaces takes place which is unnecessary.
- The most harmful part of PAM is that metallurgical changes takes place on the surface.
- The operator or person handling the whole process must take proper precautions. This process can affect human eyes so a proper googles or helmet must be worn by an operator.

Applications

- It is mostly used for cryogenic, high temperature corrosion resistant alloys.
- It is also used in case of titanium plate up to 8mm thickness.
- PAM is used in nuclear submarine pipe system and for welding steel rocket motor case.
- PAM is prominent for the applications related to stainless tube and tube mills.