NONTRADITIONAL MACHINING

INTRODUCTION

Machining processes that involve chip formation have a number of inherent limitations which limit their application in industry. Large amounts of energy are expended to produce unwanted chips which must be removed and discarded. Much of the machining energy ends up as undesirable heat that often produces problems of distortion and surface cracking. Cutting forces require that the workpiece be held which can also lead distortion. Unwanted distortion, residual stress, and burrs caused by the machining process often require further processing. Finally, some geometries are too delicate to machine while others are too complex. Figure 28.1 shows some geometries which are difficult to machine by conventional methods.

In view of these limitations, many *nontraditional machining* (NTM) methods h been developed since World War II to address the growing list of machining requirement which cannot be handled by conventional machining alone. Advantages of NTM methods may include the ability to machine:

- Complex geometries beyond simple planar or cylindrical features
- Parts with extreme surface finish and tolerance requirements
- Delicate components that cannot withstand large cutting forces
- Parts without producing burrs or inducing residual stresses
- Brittle materials or materials with very high hardness

For the purposes of our discussion, NTM processes can be divided into four groups based upon the material removal mechanism:

1. ***Chemical-Chemical*** reaction between a liquid reagent and the workpiece results in etching.
2. ***Electrochemical***- An electrolytic reaction at the workpiece surface is responsible material removal.
3. ***Mechanical***- High *velocity* abrasives or liquids remove material.
4. ***Thermal***- High temperatures in very localized regions evaporate materials.

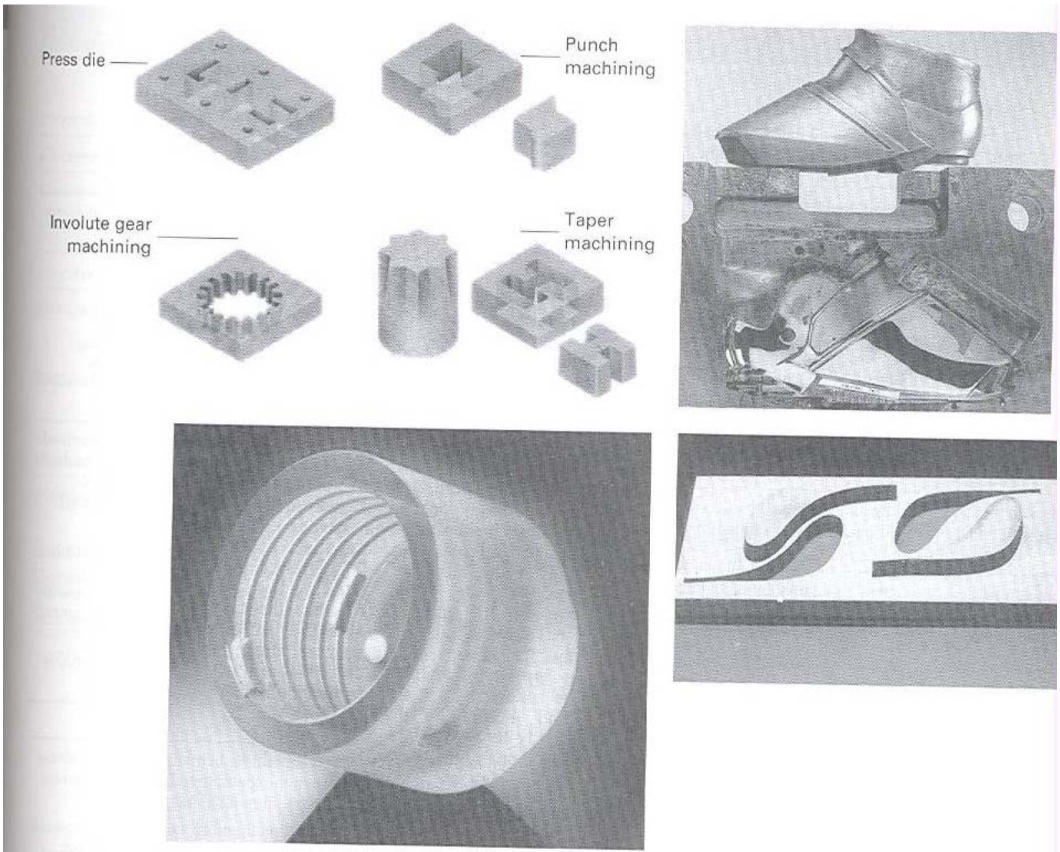


FIGURE 28-1 Nontraditional machining techniques and geometries: (*Top left*) Some difficult-to-machine shapes produced by wire EDM. (*Top right*) Injection mold for a ski boot made in hard tool steel by EDM—note superior surface finish. (*Bottom left*) A quartz housing with two internal grooves cut with ultrasonics. (*Bottom right*) Contour cut turbine blade profile made by CO_2 laser.

In comparison, NTM processes typically have lower feed rates and require more power consumption when compared to machining. However, some processes permit batch processing which increases the overall throughput of these processes and enables them to compete with machining. A major advantage of some NTM processes is that feed rate is independent of the material being processed. As a result, these processes are often used for difficult to machine materials.

NTM processes typically have better accuracy and surface finish with the ability of some processes to machine larger feature sizes at lower capital costs. In most applications, NTM requires part specific tooling while general purpose cutting and work holding tools make machining very flexible.

ELECTROCHEMICAL MACHINING

Electrochemical machining, commonly designated ECM, removes material by anodic solution with a rapidly flowing electrolyte. It is basically a de-plating process in which

TOOL IS THE CATHODE AND THE WORKPIECE IS THE ANODE; BOTH MUST BE ELECTRICALLY CONDUCTIVE. THE ELECTROLYTE, WHICH CAN BE PUMPED RAPIDLY THROUGH OR AROUND THE TOOL, SWEEPS AWAY ANY HEAT AND WASTE PRODUCT (SLUDGE) GIVEN OFF DURING THE REACTION. THE SLUDGE IS CAPTURED AND REMOVED FROM THE ELECTROLYTE THROUGH FILTRATION. THE SHAPE OF THE CAVITY IS DEFINED BY THE TOOL WHICH IS ADVANCED BY MEANS OF A SERVOMECHANISM THAT CONTROLS THE GAP BETWEEN THE ELECTRODES (I.E., THE INTERELECTRODE GAP) TO A RANGE FROM 0.076 TO 0.76 MM. (0.25 MM TYPICAL). THE TOOL ADVANCES INTO THE WORK AT A CONSTANT FEED RATE, OR PENETRATION RATE, MATCHES THE DE-PLATING RATE OF THE WORKPIECE. THE ELECTROLYTE IS A HIGHLY CONDUCTIVE SOLUTION OF INORGANIC SALT, USUALLY $NaCl$, KCl, and $NaN0_3$ IS OPERATED AT ABOUT 24 TO 65 °C WITH FLOW RATES RANGING FROM 15 TO 61 M/SEC. THE TEMPERATURE OF THE ELECTROLYTE IS MAINTAINED THROUGH APPROPRIATE TEMPERATURE CONTROLS. TOOLS ARE USUALLY MADE OF COPPER OR BRASS AND SOMETIMES STAINLESS STEEL. THE PROCESS IS SCHEMATICALLY IN FIGURE 28-11.

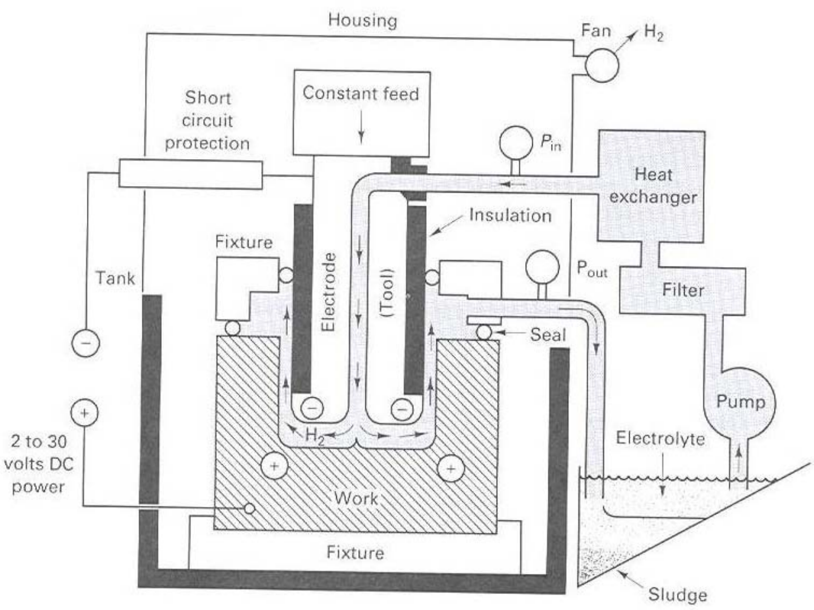


FIGURE 28-11 Schematic diagram of electrochemical machining process (ECM).

MECHANICAL NTM PROCESSES

ULTRASONIC MACHINING

Ultrasonic machining (USM), sometimes called *ultrasonic impact grinding,* employs ultrasonically vibrating tool to impel the abrasives in a slurry at high velocity against workpiece. The tool is fed into the part as it vibrates along an axis parallel to the tool feed at an amplitude on the order of several thousandths of an inch and a frequency of 20 kHz. As the tool is fed into the workpiece, a negative of the tool is machined into the work piece. The cutting action is performed by the abrasives in the slurry which is continuously flooded under the tool. The slurry is loaded up to 60% by weight with abrasive particles. Lighter abrasive loadings are used to facilitate the flow of the slurry for deep drilling (to 5mm deep). Boron carbide, aluminum oxide, and silicon carbide are the most common used abrasives in grit sizes ranging from 400 to 2000. The amplitude of the vibration should be set approximately to the size of the grit. The process can use shaped tools cut virtually any material but is most effective on materials with hardness greater than Rc 40 including brittle and non conductive materials such as glass. Figure 28-15 shows a simple schematic of this process.

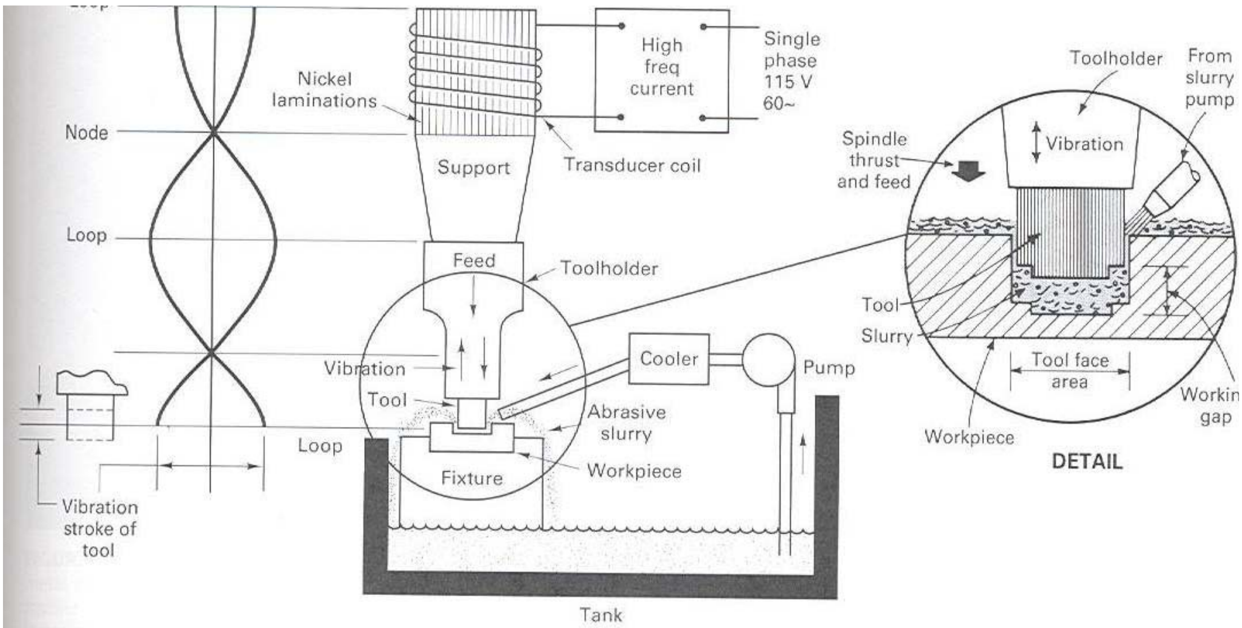


FIGURE 28-15 Sinking a hole in a workpiece by ultrasonic machining.

WATERJET CUTTING

Waterjet cutting (WJC), also known as *water jet machining* or *hydrodynamic machining,* uses a high-velocity fluid jet impinging on the workpiece to perform a slitting operation (Figure 28-16). Water is ejected from a nozzle orifice at high pressure (up to 60,000 psi). The jet is typically 0.076 to 0.5 mm in diameter and exits the orifice at velocities up to 900 m/sec. Key process parameters include water pressure, orifice diameter, water flow rate, and working distance (distance between the workpiece and the nozzle). Nozzle materials include synthetic sapphire due to its machinability and resistance to wear. Tool life on the order of several hundred hours is typical. Mechanisms for

tool failure include chipping from contaminants or constriction due to mineral deposits. This emphasizes the need for high levels of filtration prior to pressure intensification.

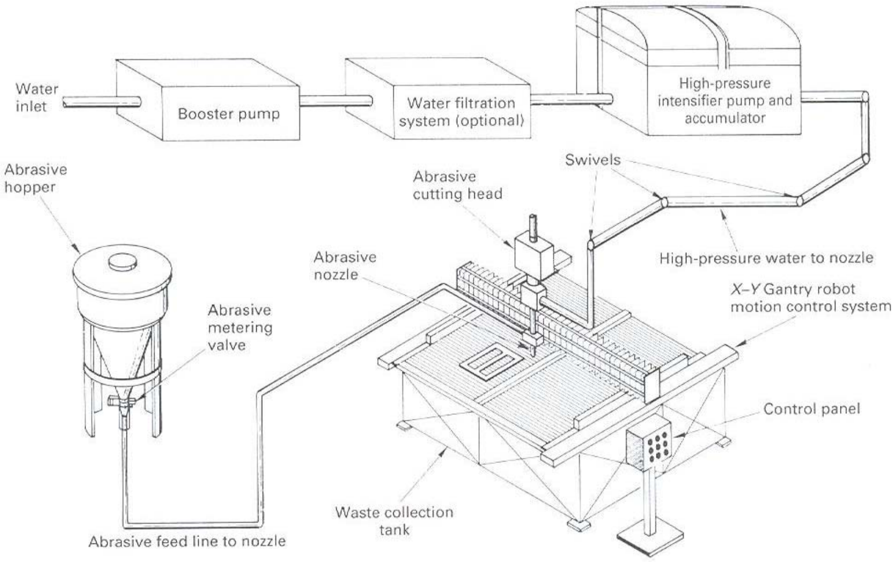


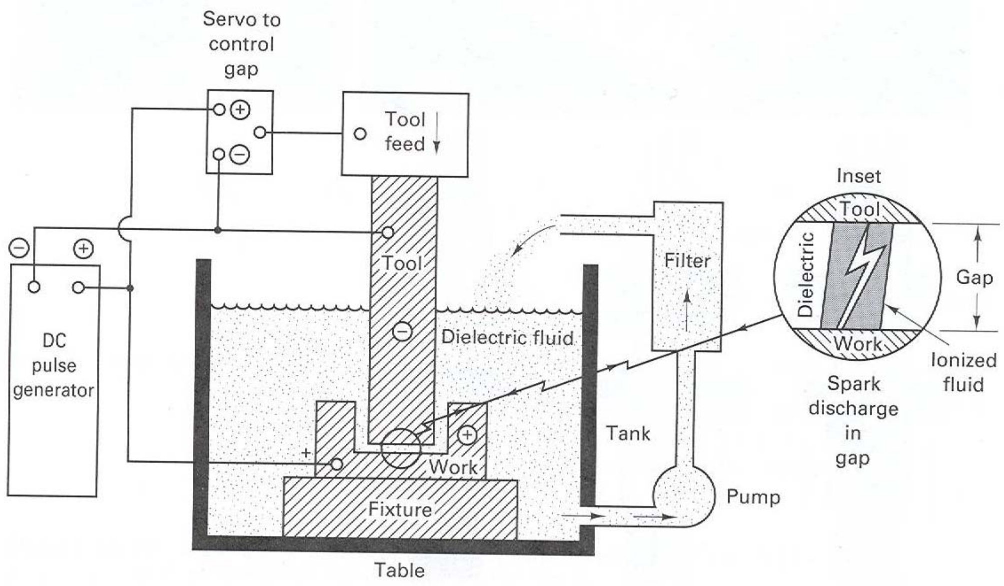
Figure 28-16: Schematic diagram of hydrodynamic jet machining. The intensifier elevates the fluid to the desired nozzle pressure while accumulator smoothes out pulses in the fluid jet.

THERMAL NTM PROCESSES

Electrical Discharge Machining [EDM]

EDM processes remove metal by discharging electric current from a pulsating DC power supply across a thin interelectrode gap between the tool and the workpiece. See Figure 28-21 for a schematic.

FIGURE 28-21 EDM or spark erosion machining of metal, using high-frequency spark discharges in a dielectric, between the shaped tool (cathode) and the work (anode). The table can make *X–Y* movements.



The gap is filled by a dielectric fluid which becomes locally ionized at the point where the interelectrode gap is the narrowest, generally, where a high point on the workpiece comes close to a high point on the tool.
The ionization of the dielectric fluid creates a conduction path in which a spark is produced. The spark produces a tiny crater in the workpiece by melting and vaporization, and consequently tiny, spherical "chips" are produced by re-solidification of the melted quantity of workpiece material. Bubbles from discharge gases are also produced. In addition to machining the workpiece, the high temperatures created by the spark also melt or vaporize the tool creating tool wear. The dielectric fluid is pumped through the interelectrode gap and flushes out chips and bubbles while confining the sparks. **Once the highest point on the workpiece removed, a subsequent spark is created between the tool and the next highest point and the process proceeds into the workpiece. Literally hundreds of thousands of sparks may generated per second. This material removal mechanism is described as *spark erosion.***

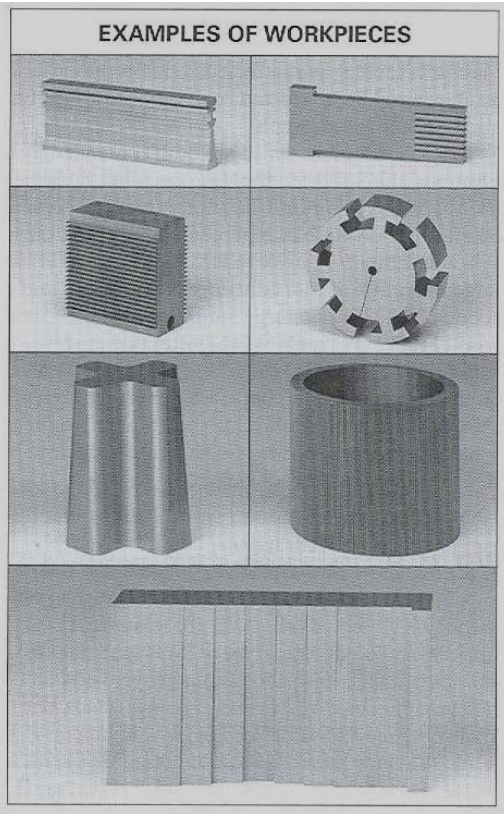
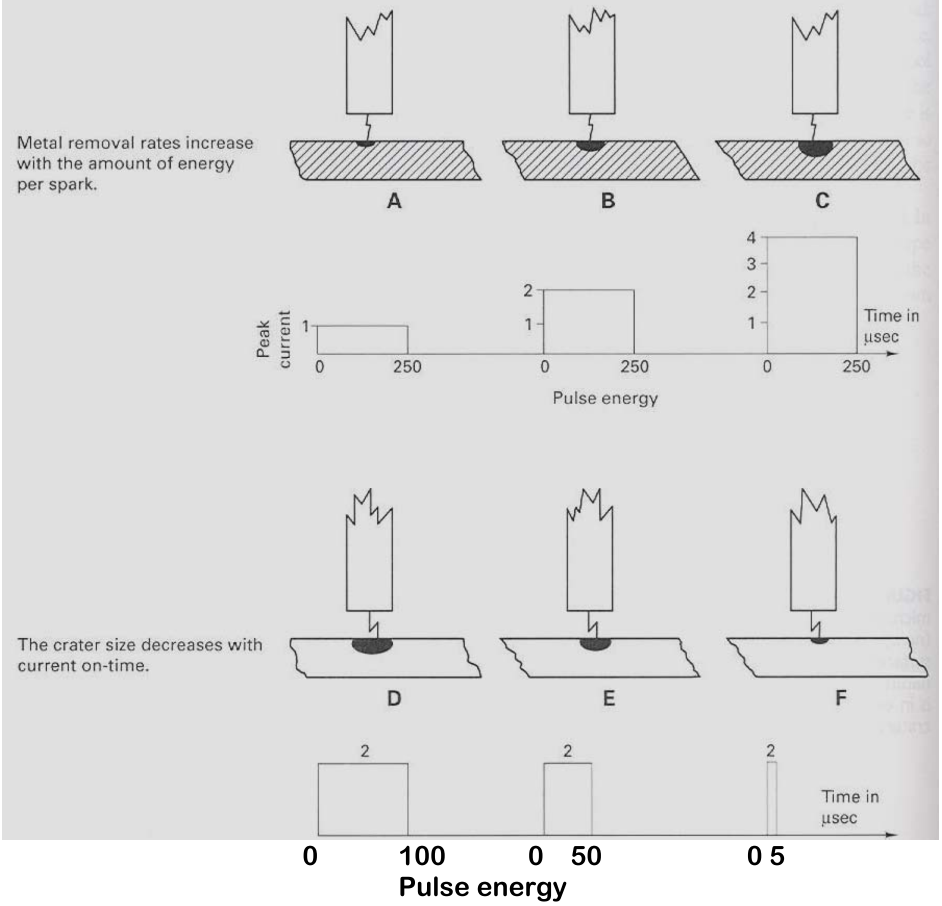


FIGURE 28-22 Examples of wire EDM workpieces made on NC machine (Hatachi).

MRR and surface finish are both controlled by the spark energy. In modern EDM equipment, the spark energy is controlled by a dc power supply. The power supply works by pulsing on and off the current at certain frequencies (between 10 and 500 kHz). The on-time as a percentage of the total cycle time (inverse of the frequency) is called the *duty cycle*. EDM power supplies must be able to control the pulse voltage, current, duration, duty cycle, frequency, and electrode polarity.

The power supply controls the spark energy mainly by two parameters: current on-time and discharge current. Figure 28-24 shows the effect of current on-time and discharge current on crater size. Larger craters are good for high MRRs. Conversely, small craters are good for finishing operations. Therefore, generally, higher duty cycles and lower frequencies are used to maximize MRR. Further, higher frequencies and lower discharge currents are used to improve surface finish while reducing the MRR. Higher frequencies generally cause increased tool wear.

FIGURE 28-24 The principles of metal removal for EDM.



Wire EDM.

Wire EDM, shown in Figure 28-25, involves the use of a continuously moving conductive wire as the tool electrode. The tensioned wire of copper, brass, tungsten, or molybdenum is used only once, travelling from a take-off spool to a take-up spool while being "guided" to produce a straight narrow kerf in plates up to 75 mm thick. The wire diameter ranges from 0.05 to 0.25 mm with positioning accuracy up to ± 0.005 mm in machines with NC. The dielectric is usually deionized water because of its low viscosity. This process is widely used for the manufacture of punches, dies, and stripper plates, with modern machines capable of routinely cutting die relief, intricate openings, tight radius contours, and corners.

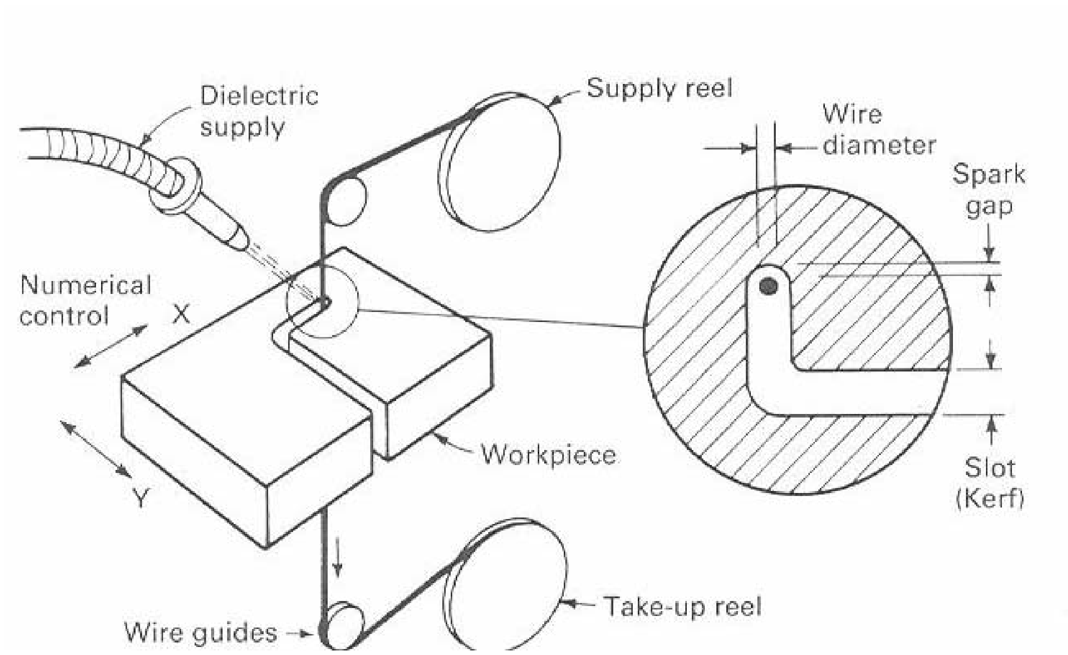


Figure 28-25 Schematic diagram of equipment for wire EDM using a moving wire electrode.

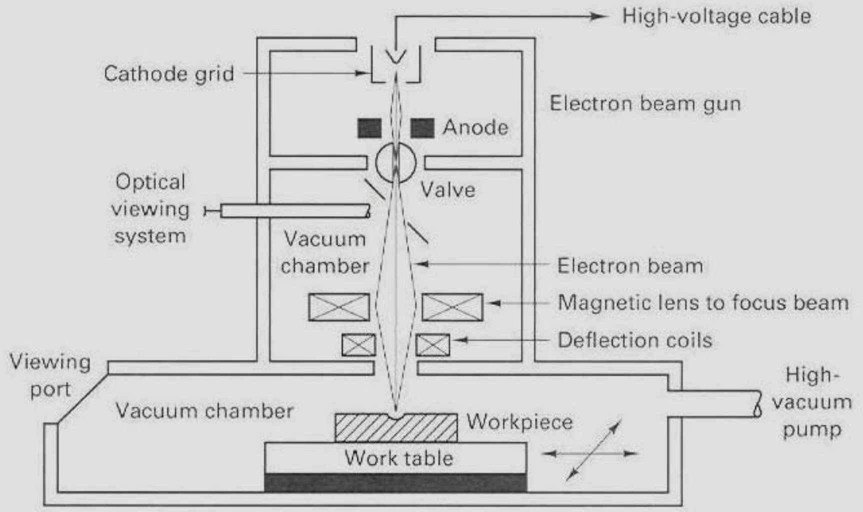
Advantages and Disadvantages of *EDM*

EDM is applicable to all materials that are fairly good electrical conductors, including metals, alloys and most carbides. The hard ness, toughness, or brittleness of the material imposes no limitations. EDM provides a relatively simple method for making holes and pockets of any desired cross section in materials that are too hard or too brittle to be machined by most other methods. The process leaves no burrs on the edges. About 80 to 90% of the EDM work performed in the world is in the manufacture of tool and die sets for injection molding, forging, stamping, and extrusions. The absence of almost all mechanical forces makes it possible to EDM fragile or delicate parts without distortion. EDM has been used in microma-chining to make feature sizes as small as 0.01 mm.

PARTICLE BEAM MACHINING

As a metals-processing tool, the electron beam is used mainly for welding, to some extent for surface hardening, and occasionally for cutting (mainly drilling). *Electron beam machining* (EBM) is a thermal process that uses a beam of high-energy electrons focused on the workpiece to melt and vaporize metal. This process shown in Figure 28-26 is performed in a vacuum chamber (10-5 torr), The electron beam is produced in the electron gun (also under vaccum) by thermionic emission. In its simplest form, a filament (tungsten) is heated to temperatures in excess of2000°C where a stream (beam) of electrons (more than 1 billion per second) is emitted from the tip of the filament. Electrostatic optics are used to focus and direct the beam. The desired beam path can be programmed with a computer to produce any desired pattern in the workpiece. The diameter of the beam is on the order of 0.012 to 0.025 mm, and holes or narrow slits with depth-to-width ratios of 100:1 can be "machined" with great precision in any material. The interaction of the beam with the surface produces dangerous X-rays; therefore, electromagnetic shielding of the process is necessary. The layer of recast material and the depth of the heat damage are very small. For micromachining applications, MRRs can exceed that of EDM or ECM, Typical tolerances are about 10% of the hole diameter or slot width. These machines require high voltages (50 to 200 kV) to accelerate the electrons to speeds of 0,5 to 0.8 the speed of light and should be operated by fully trained personnel.

FIGURE 28-26 Electron beam machining uses high-energy electron beam (10^9 W/in^2) to melt and vaporize metal in 0.001-in.-diameter spots.



LASER BEAM MACHINING

Laser beam machining (LBM) uses an intensely focused, coherent stream of light (a laser) to vaporize or chemically *ablate* materials. A schematic of the LBM process is shown in Figure 28-27. Lasers are also used for joining (welding, brazing, soldering), heat treating materials. Power density and interaction time are the basic parameters in laser processing as shown in Figure 28-28. Drilling requires higher power densities and shorter interaction times compared to most other applications.

The material removal mechanism in LBM is dependent upon the wavelength of the laser used.

Laser light is produced within a laser cavity which is a highly reflective cavity containing a laser rod and a high intensity light source, or laser lamp. The light source is used to "pump up" the laser rod which includes atoms of a lasing media which is capable of absorbing the particular wavelength of light produced by the light source.

When an atom of lasing media is struck by a photon of light, it becomes energized. When a second photon strikes the energized atom, the atom gives off two photons of identical wavelength moving in the same direction and with the same phase. This process is called *stimulated emission.*

As the two photons now stimulate further emission from other energized atoms, a cascading of stimulated emission ensues. To increase the number of stimulated emissions, the laser rod has mirrors on both ends that are precisely parallel to one another. Only photons moving perpendicular to these two mirrors stay within the laser rod causing additional stimulated emission. One of the mirrors is partially transmissive and permits some percent of the laser energy to escape the cavity. The energy leaving the laser rod is the laser beam.

The most common industrial laser is the CO_2 laser. The CO_2 laser is a gas laser which uses a tube of helium and carbon dioxide as the laser rod. Output is in the far infrared range (10.6 μm) and the power can be up to 10 kW. Nd:YAG lasers are called solid state lasers. The laser rod in these lasers is a solid crystal of yttrium, aluminium, and garnet which has been doped with neodymium atoms (the lasing media). The output wavelength is in the near infrared range (1064 nm) and power up to 500 W is common.

Lasers produce highly collimated, coherent (in phase) light which when focused to a small diameter produce high power densities which are good for machining. It is generally accepted that in order to evaporate materials, infrared power densities in excess of 105 W /mm^2 are needed. For CO_2 lasers, these levels are directly achievable. However, in Nd: YAG lasers, these high power conditions would significantly decrease the life of the laser lamp.

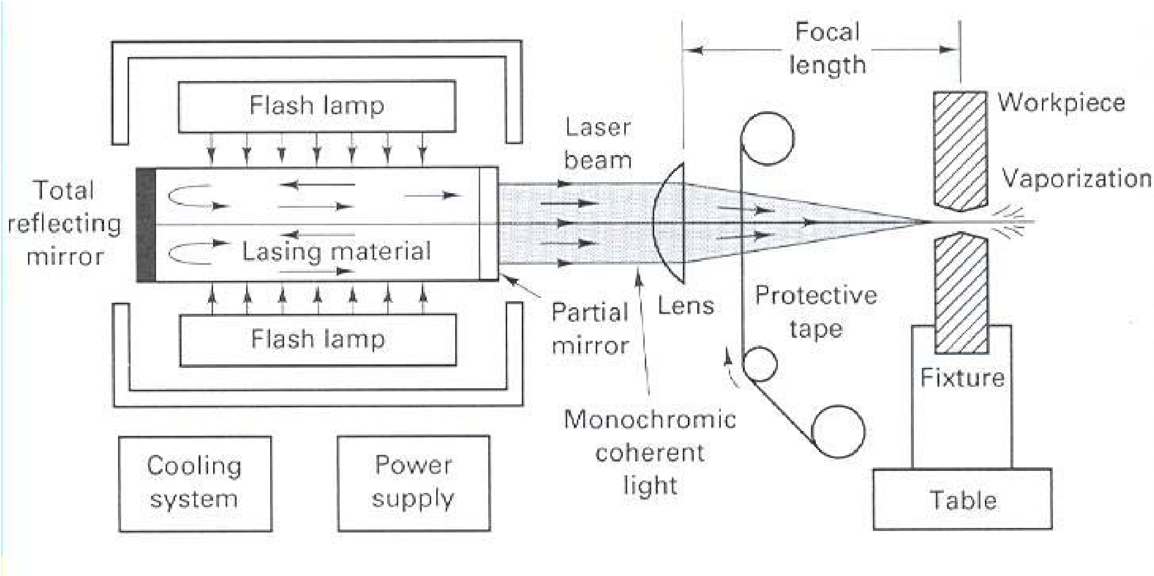


Figure 28-27 Schematic diagram of a laser beam machine, a thermal NTM process that can micromachine any material.

FIGURE 28-28 Power densities and interaction times in laser processing vary with the application.