Electron Beam Machining (EBM)

Synopsis

- Introduction
- Principle
- Characteristics of EBM
- Equipment – gun construction
- Types of gun (vacuum system)
- Beam control
- Process parameters
- Advantages
- Limitations
- Applications

Introduction

- Invented in Germany in 1952
- Thermal material removal process that utilizes a focused beam of high-velocity electrons to perform high-speed drilling and cutting
- Types: Thermal (beam is used to heat the material up to the point where it is selectively vaporized) and non-thermal (utilizes the beam to cause a chemical reaction)
- Able to drill materials up to 10mm thick at perforation rates that far exceed all other manufacturing processes
- Although EBM is capable of producing almost any programmable hole shape, it is often applied for high-speed drilling of round holes in metals, ceramics and plastics of any hardness

Principle

- A stream of high-speed electrons impinges on the work surface whereby the kinetic energy, transferred to the work material, produces intense heating. Depending on the intensity of the heat thus generated, the material can melt or vaporize

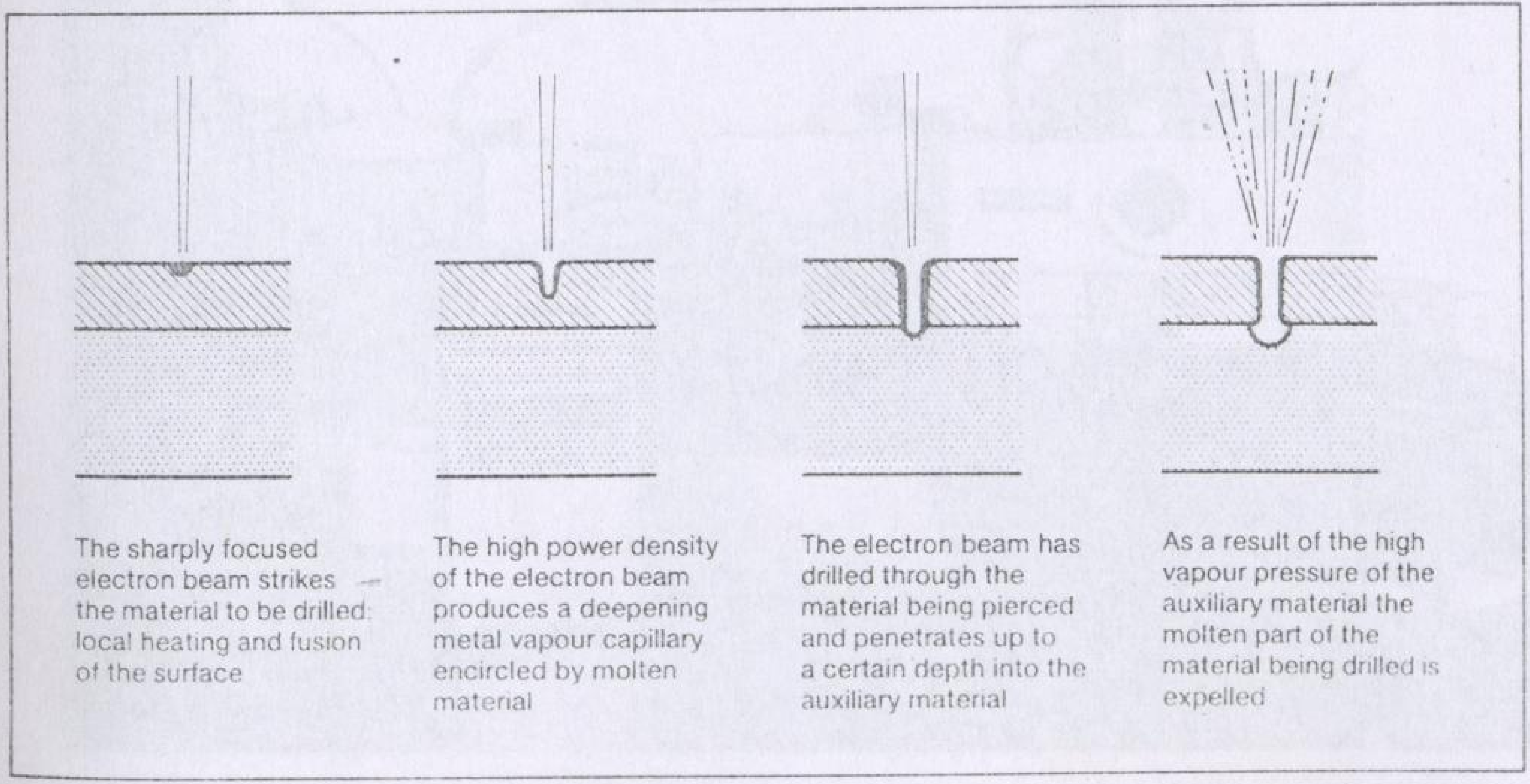


Figure 19.1 The four steps that lead to material removal by electron beam drilling (*Source*: courtesy, Messer Griesheim GmbH, Puchheim, W. Ger.).

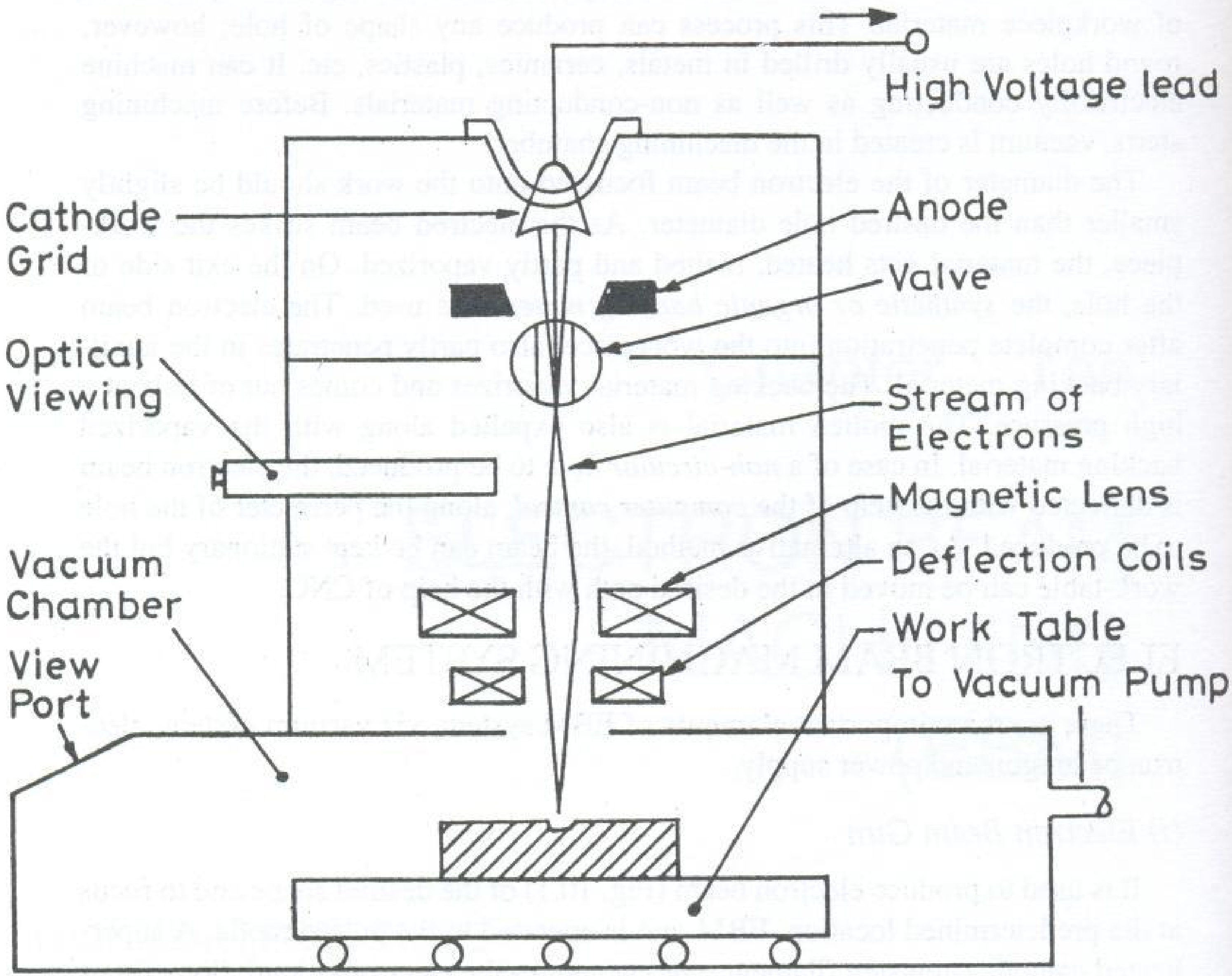
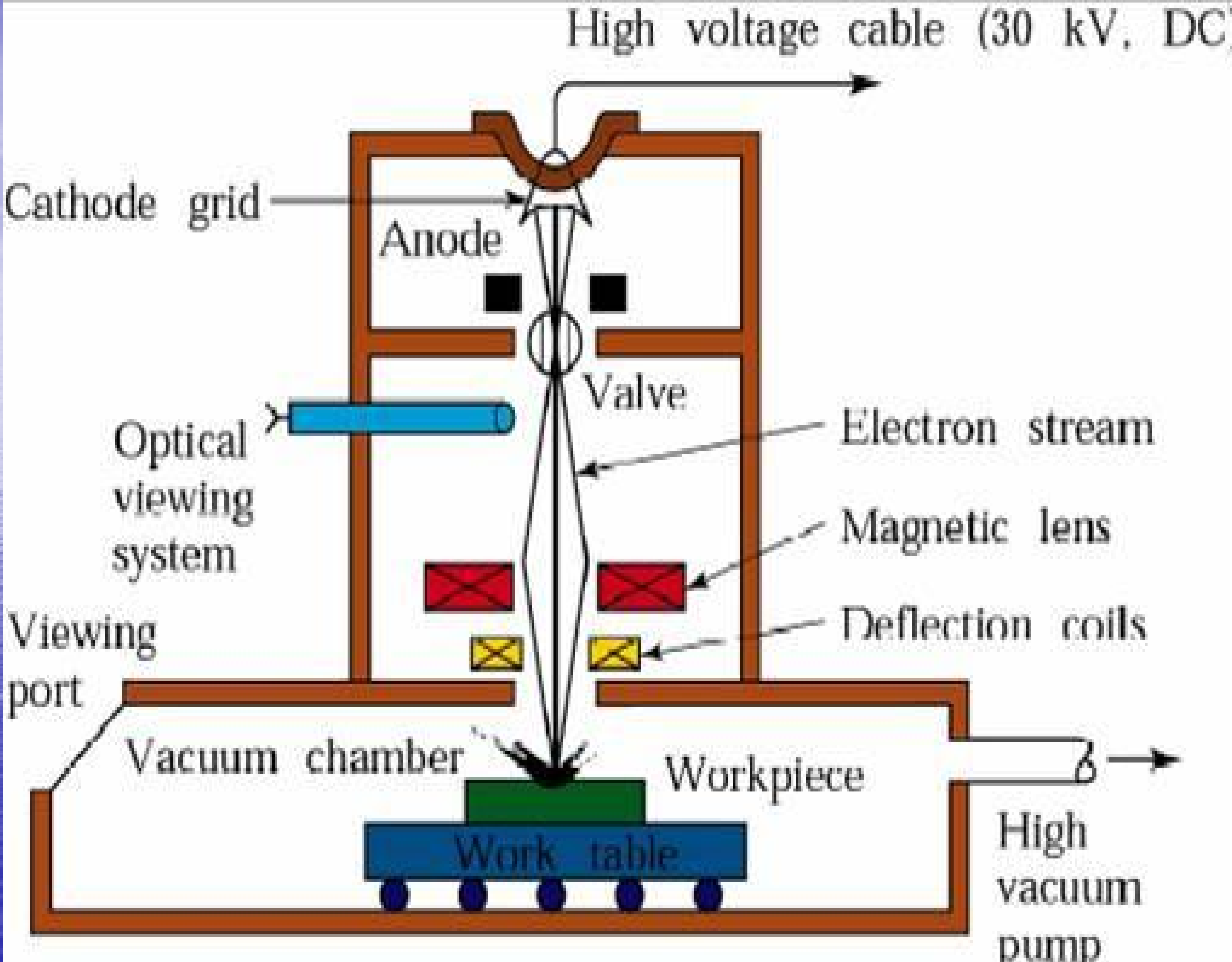


Fig. 10.1 Schematic diagram of electron beam machining system.


High voltage cable (30 kV, DC)
Cathode grid
Anode
Valve
Optical viewing system
Electron stream
Magnetic lens
Deflection coils
Viewing port
Vacuum chamber
Workpiece
Work table
High vacuum pump

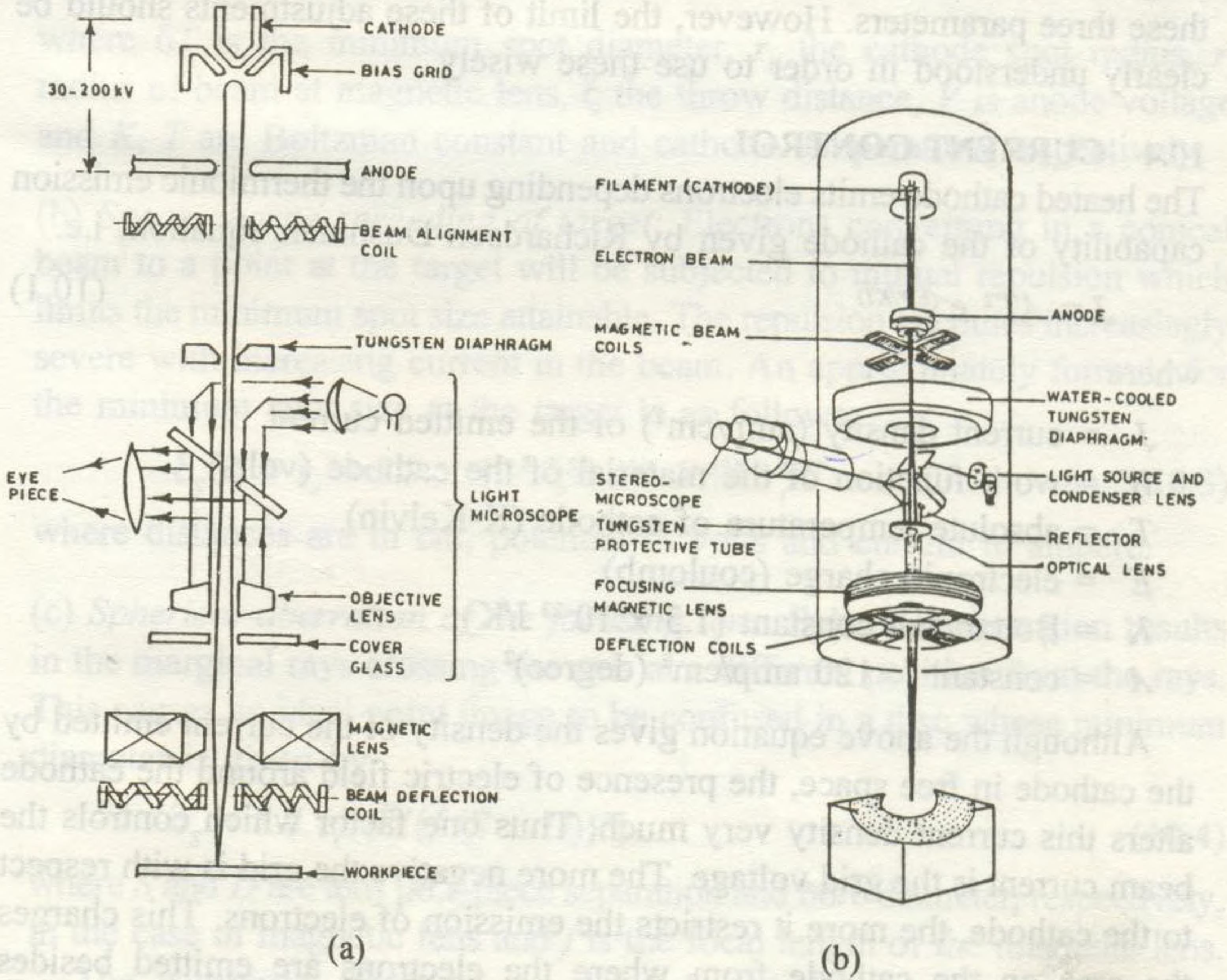


Fig. 10.1 Electron Beam Gun Construction Scheme

Major components of the system

- Three important elements of EBM system:

1. Electron beam gun: Function is to generate, shape and deflect the electron beam to drill or machine the workpiece

- The essential constituents of the electron gun are:
- Cathode- source of the electrons
- Bias Grid- to control the no. of electrons and acts as a switch for generating pulses
- Anode- to accelerate the electrons
- Magnetic coil that functions as a magnetic lens, repels and shapes the electron beam into a converging beam
- Tungsten diaphragm- removes stray electrons and cools the set-up
- Rotating slotting disks mounted directly below the gun exit opening to protect the EBM gun from metal spatter and vapor
- Light microscope- to view the machining area
- Three magnetic coils : Magnetic lens, deflection coil and stigmator that are respectively used to focus the beam, small amount of controllable beam deflection and to correct minor beam aberrations and ensures a round beam at the workpiece

Major components of the system

2. Power supply: voltages of up to 150kV is generated to accelerate the electrons;

- All power supply variables are controlled by a microcomputer
- To ensure process repeatability, the process variables are monitored and compared with set-points by the power supply computer. If a discrepancy arises, the operator is alerted

3. Vacuum system and machining chamber:

- A vacuum chamber is required for EBM and should have a volume of at least 1m^3 to minimize the chance of spatter sticking to the chamber walls
- Inside the chamber a positioning system is used for the controlled manipulation of the workpiece
- The positioning system may be as simple as a single, motor-driven rotary axis or as complex as a fully CNC, closed-loop, five-axis system

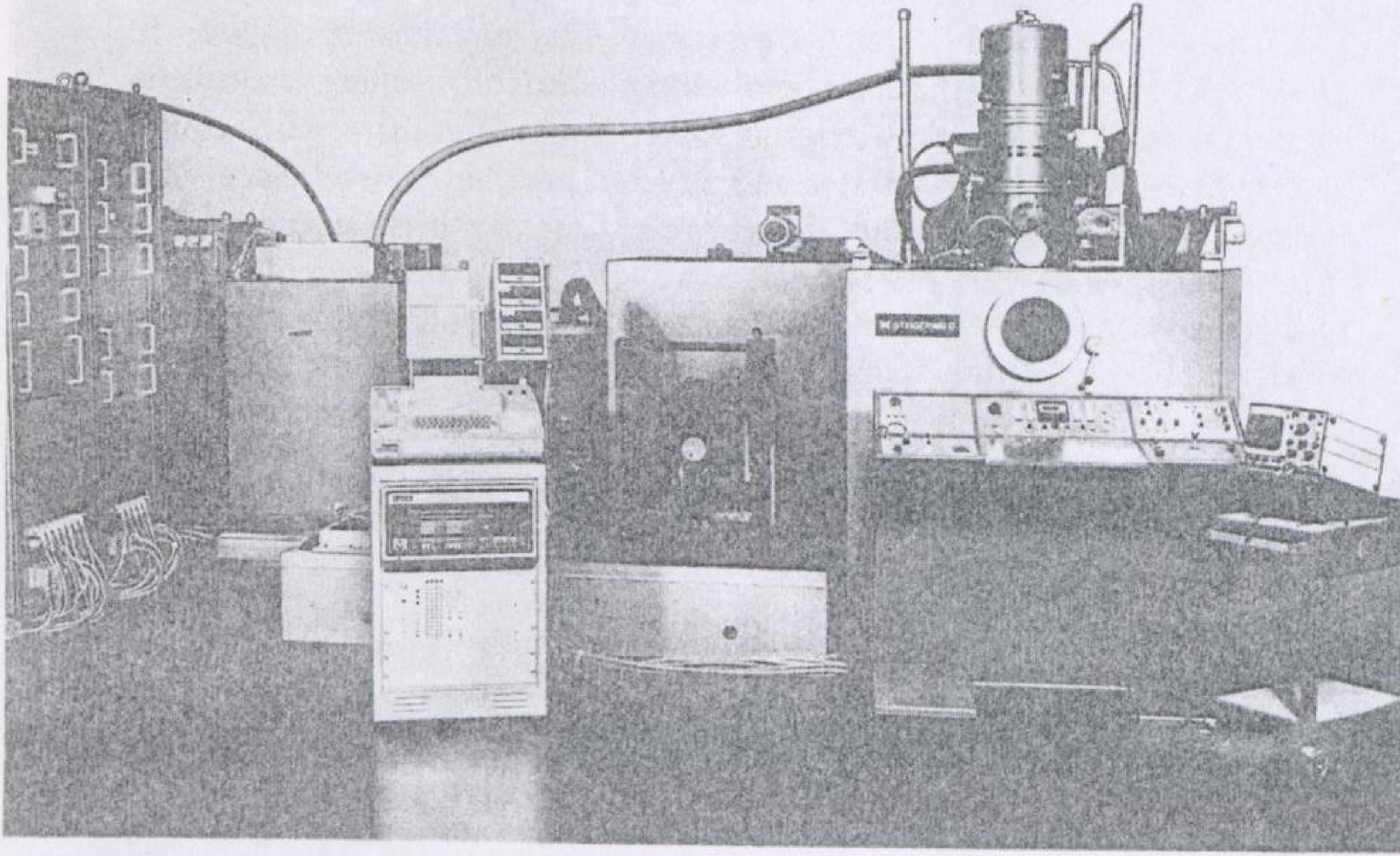
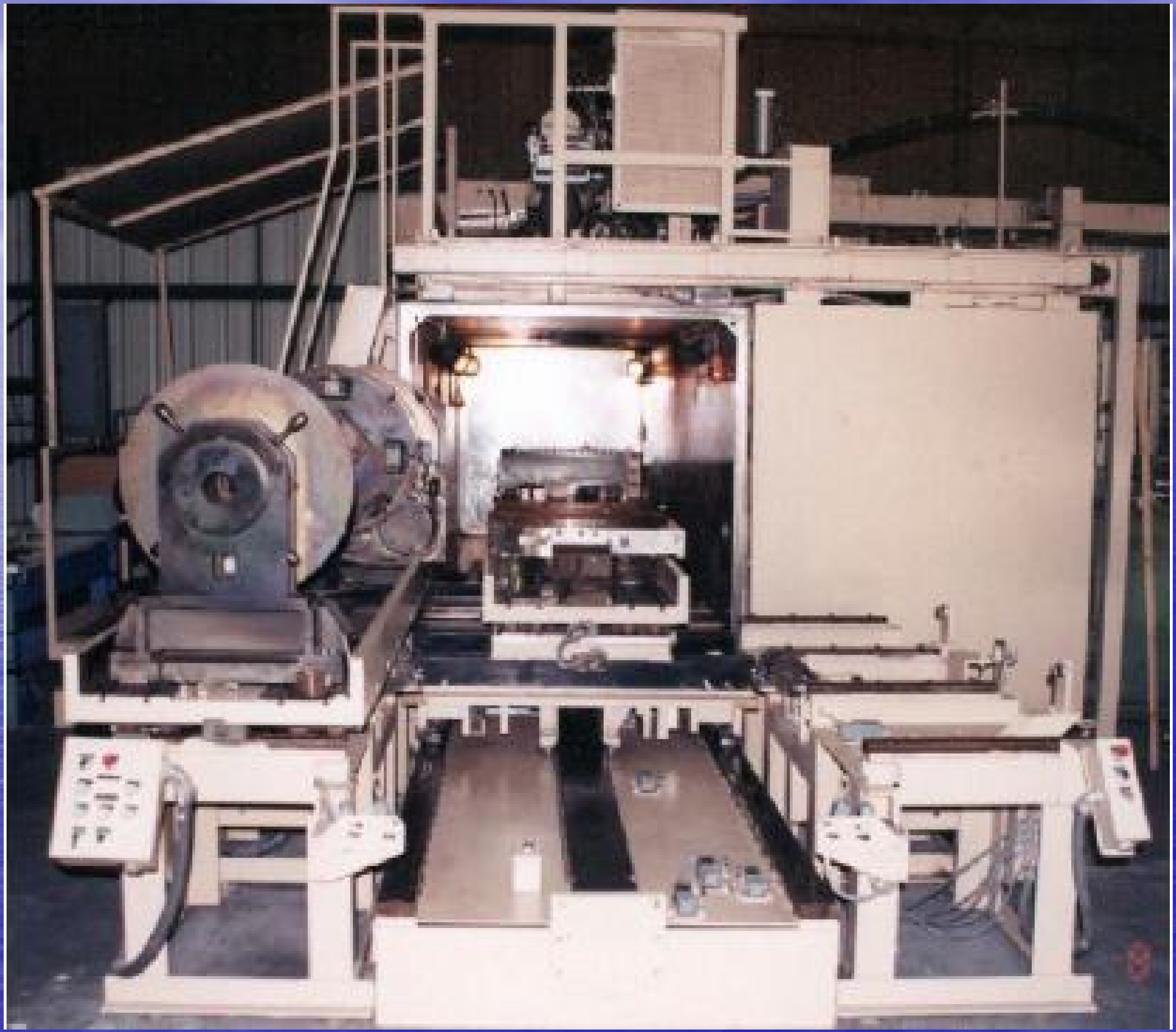


Figure 19.2 Computer-controlled multiaxis EBM system (*Source*: courtesy, Messer Griesheim GmbH, Puchheim, W. Ger.).



Characteristics of EBM

- Important characteristic: high resolution and the long depth of field that is obtained because of the short wavelength of high energy electrons;
- Extraordinary energy (power densities of 10^6 kW/cm2 have been achieved)
- Ability to catalyze many chemical reactions, controllability and compatability with high vacuum
- For conductive as well as non-conductive materials
- At entry side of beam, a small burr
- Workpiece material properties do not affect performance
- Small diameter holes (0.1 to 1.4mm)
- Aspect ratio = 15:1
- No mechanical force and hence fragile, thin, low strength components can be easily machined
- Off-axis holes easily made
- Residual thermal stresses generated on the workpiece due to high temperature gradient
- Very high investment cost
- Skilled operator is required
- HAZ

Types of vacuum system

1. High vacuum (HV)
2. Medium vacuum (MV)
3. Non vacuum (NV)

- Still requires a high vacuum in the electron gun, but deliver the beam to a workpiece at atmospheric pressure, thus avoiding non-productive pumpdown cycles completely
- Construction much different from the HV
- The beam path from the cathode consists of a series of individually pumped stages that are all connected by small apertures – this construction produces a pressure gradient that ranges from atmospheric pressure to high vacuum
- Although NV system can increase productivity dramatically, they are somewhat limited since the interaction of the electron beam with air spreads and diffuses the beam thus lowering the power density at the workpiece – this results in an increase of the thermal effects of the process, the effects are still far less than those of conventional processes
- Standoff distance between the gun and the workpeice is limited to a maximum of 19mm

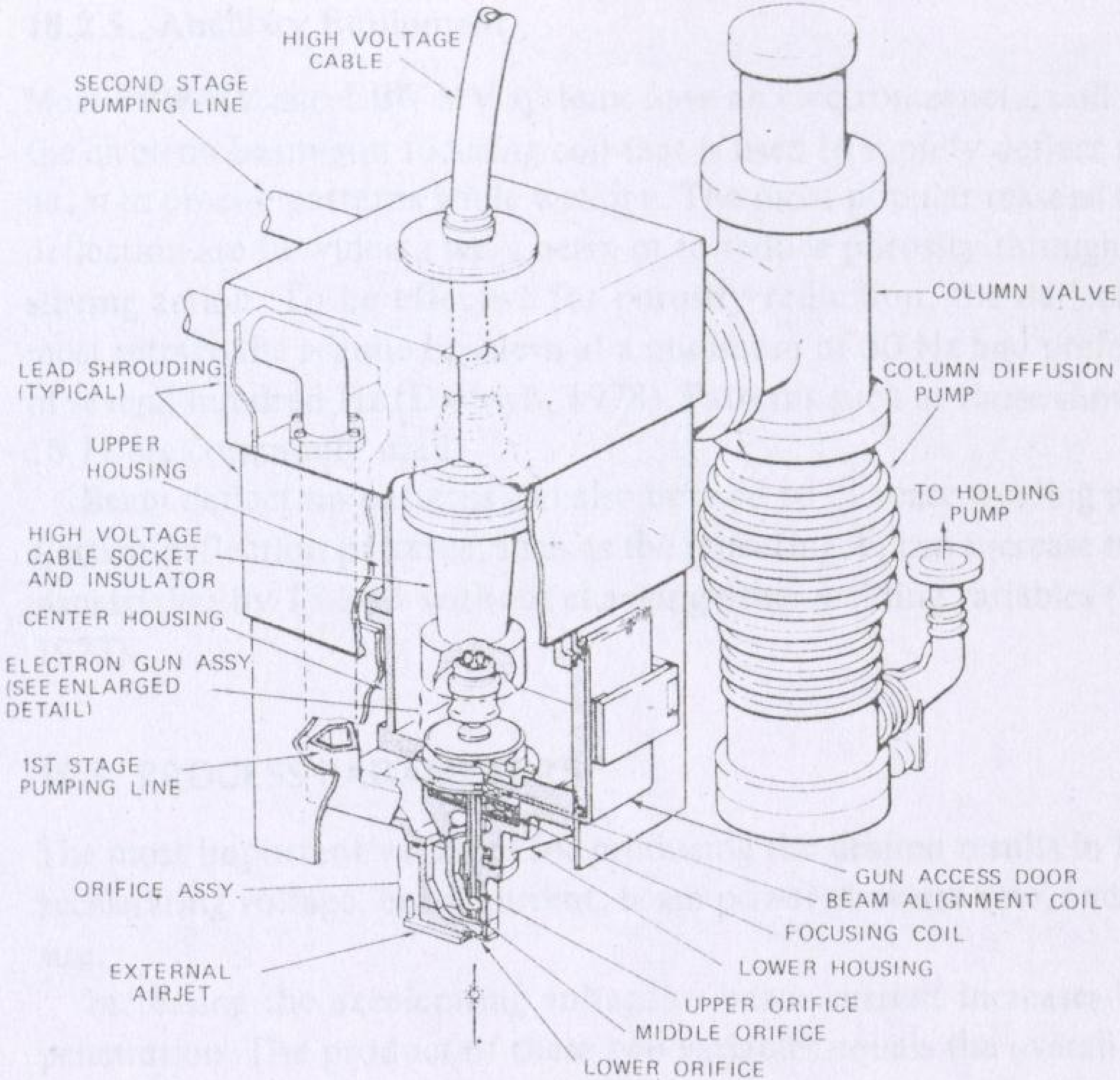


Figure 18.9 Construction of EBW-NV assembly (*Source*: courtesy, Leybold-Heraeus Vacuum Systems, Inc., Enfield, Conn.).

Beam control

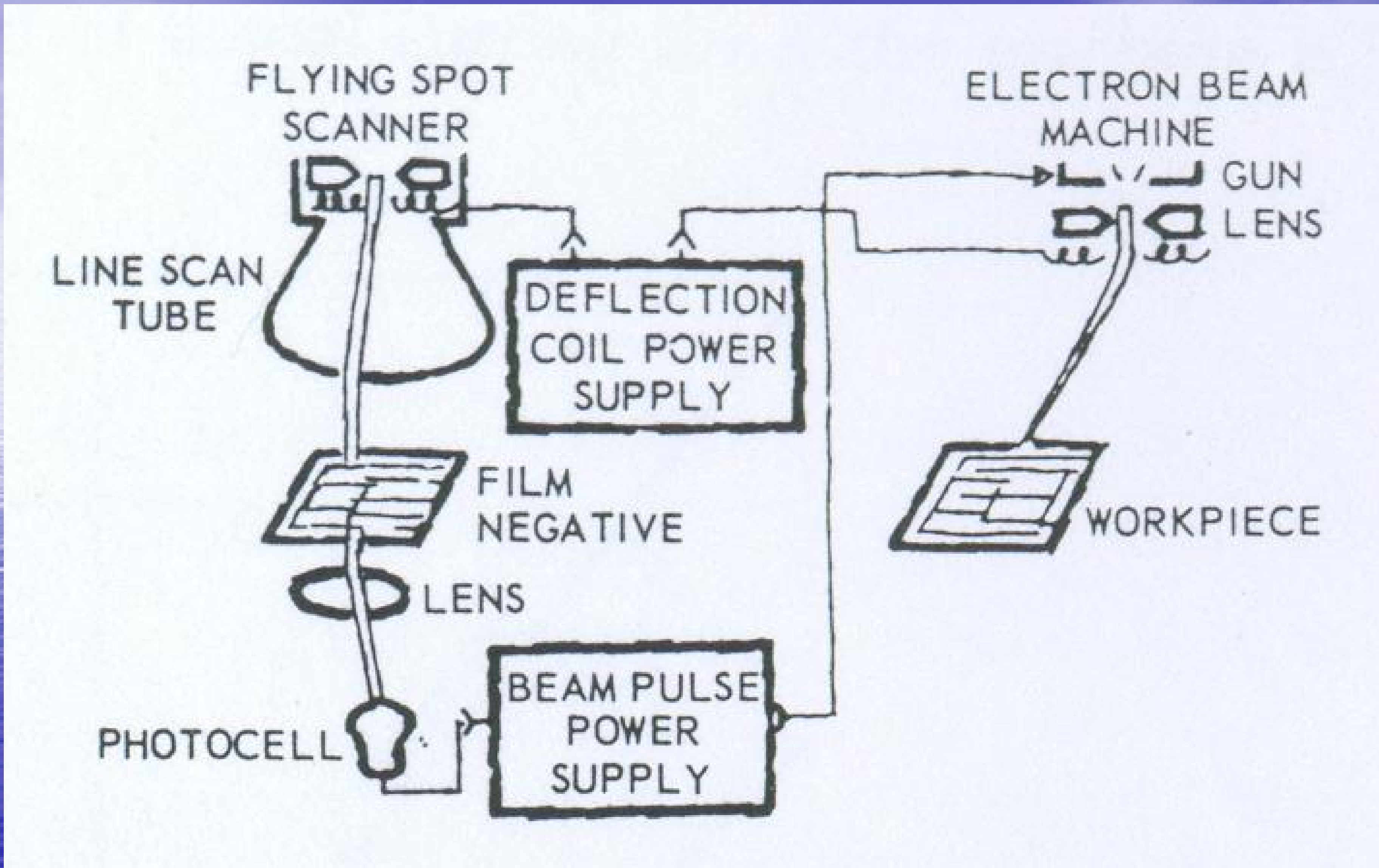
- The electron beam is controlled with optical precision
- The beam consists of negatively charged particles whose energy content is determined by the mass and velocity of the individual particles.
- The negatively charged particles can be accelerated in an electrostatic field to extreme high velocities. During the process, the specific energy content of the electron beam can be increased beyond the emission energy, thus producing a beam of energy, the intensity of which far exceeds that obtainable from light.
- Due to the precise electron optics, large amounts of energy can be manipulated with optical precision.

1. **Electromagnetic lens:**

- Before the electrons collide with the workpiece, a variable strength electromagnetic lens is used to refocus the beam to any desired diameter down to less than 0.025 mm at a precise location on the workpiece and thus attains an extremely high power density.
- This extremely, high power density immediately vaporizes any material on which the beam impinges.

2. Magnetic deflection coil:

- Mounted below the magnetic lens, is used to bend the beam and direct it over the desired surface of the workpiece. This deflection system permits programming of the beam in any specific geometrical pattern, using the proper deflection coil current input
- At the point of beam impingement, the kinetic energy in the beam is converted to thermal energy in workpiece.
- Another interesting deflection control technique is the flying spot scanner or optical tracing device. Using this device, the electron beam can be deflected to cover almost any conceivable pattern over a 0.25 sq.in. area. The desired pattern is drawn, then photographed, and the photographic negative acts as the master.
- The electron beam can also be deflected in a predetermined pattern by a relay tray or a flying spot scanner mounted in a control cabinet, which consists of a saw-tooth square wave and sine wave generator. By using this process, it is possible to drill a cross-shaped hole.


FLYING SPOT
SCANNER
ELECTRON BEAM
MACHINE
GUN
LENS
LINE SCAN
TUBE
DEFLECTION
COIL POWER
SUPPLY
FILM
NEGATIVE
WORKPIECE
LENS
BEAM PULSE
POWER
SUPPLY
PHOTOCELL

Process parameters

- Beam current, pulse duration, lens current and the beam deflection signal are the four important parameter associated with EBM

1. Beam current:

- Continuously adjustable from approximately 100µamp to 1amp
- As beam current is increased, the energy per pulse delivered to the workpiece is also increased

2. Pulse duration:

- Affects both the depth and the diameter of the hole
- The longer the pulse duration, the wider the diameter and the deeper the drilling depth capability will be
- To a degree, the amount of recast and the depth of HAZ will be governed by the pulse duration – shorter pulse durations will allow less interaction time for thermal effects to materialize
- Typical EBM systems can generate pulses as short as 50µs or as long as 10msec

Process parameters

3. Lens current:
- Determines the distance between the focal point and the electron beam gun (working distance) and also determines the size of the focused spot on the workpiece
- The diameter of the focused electron beam spot on the workpiece will, in turn, determine the diameter of the hole produced
- The depth to which the focal point is positioned beneath the workpiece surface determines the axial shape of the drilled hole
- By selecting different focal positions, the hole produced can be tapered, straight, inversely tapered or bell shaped

4. Deflection coil:
- When the hole shapes are required to be other than round, the beam deflection coil is programmed to sweep the beam in the pattern necessary to cut out the shape at the hole’s periphery
- Beam deflection is usually applicable only to shapes smaller than 6mm

Advantages

- Very high drilling rates – up to 4000 holes/sec
- Drills in many different configurations
- Drills any material - Hardness, thermal capactiy, ductility, electrical conductivity or surface properties (reflectivity) etc, are not barriers
- No mechanical distortion
- Limited thermal effects because only one pulse is required to generate each hole and pulse durations are short
- Computer controlled parameters
- High accuracy – capability to maintain high accuracy and repeatability ±0.1mm for position of the hole and ±5% for the hole diameter
- Drilling parameters can easily be changed even during drilling of single workpiece from one to the other.
- No tool wear
- Best obtainable finish, compared to the other unconventional processes used to drill precision holes
- Low operating cost

Limitations

- High capital equipment cost
- Holes produced in materials of thickness >0.13mm are tapered. So can machine thinner parts only
- Limited to 10mm material thickness
- Requires vacuum – nonproductive pump down time
- Availability limited
- Presence of a thin recast layer which may be a consideration in some applications
- High level of operator skill required
- Necessity for auxiliary backing material

Applications

- High-speed perforations in any kind of material – fluid and chemical industries use EBM to produce a multitude of holes for filters and screens
- Perforation of small diameter holes in thick materials
- Drilling of tapered holes
- Non-circular hole drilling
- Engraving of metals, ceramics and vaporised layers.
- Machining of the thin films to produce resistor networks in the IC chip manufacture

EBM drilled holes

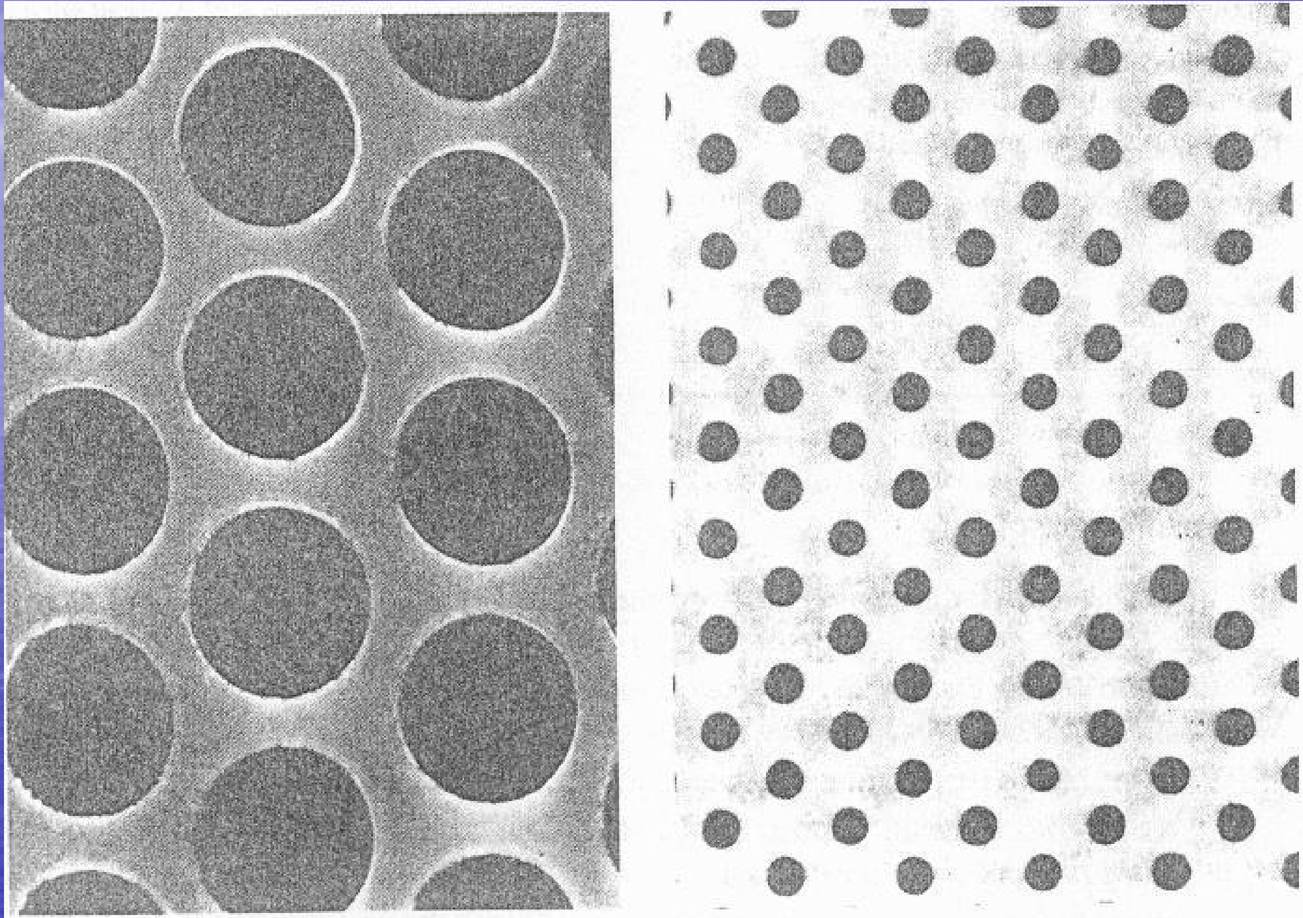
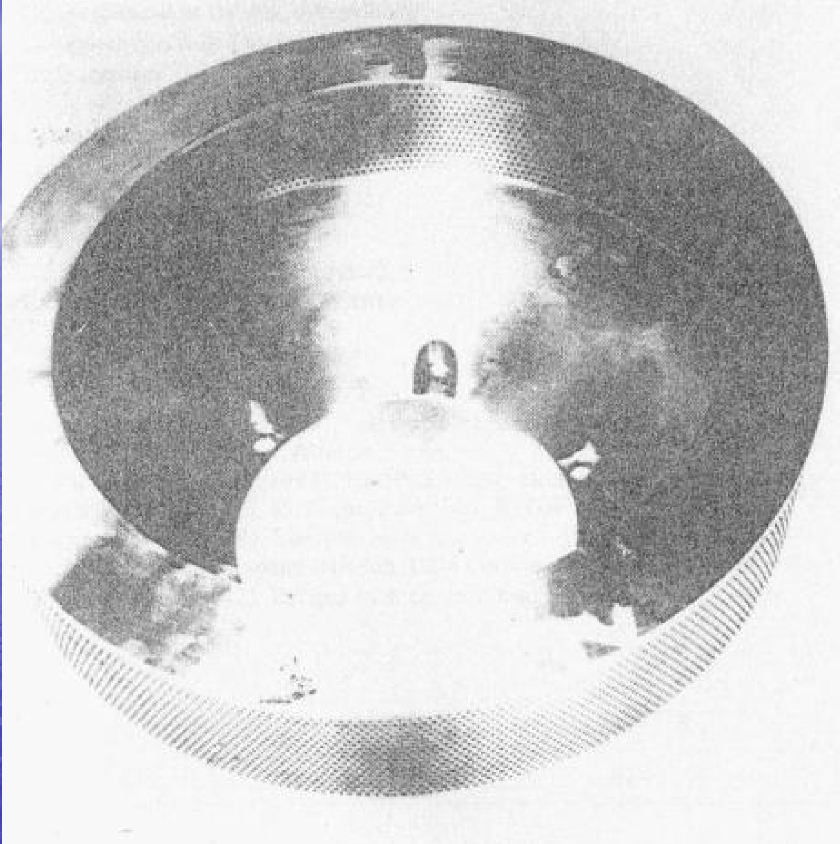


Figure 19.7 Examples of EBM-drilled holes in 1-mm thick sheet metal (10 X magnification). (*Source*: courtesy, Messer Griesheim GmbH, Puchheim, W. Ger.).

Glass fiber spinning head drilled by EBM



igure 19.6 A glass fiber spinning head by EBM drilled with 11,766 small-iameter holes at a rate of five holes per second (*Source*: courtesy, Messer riesheim GmbH, Puchheim, W. Ger.).

Dome material: Cobalt alloy steel; wall thickness: 4.3 to 6.3mm; hole dia: 0.81mm;

11,766 holes drilled in 40mins; 100 times faster than EDM; 20 to 100 times faster than laser drilling

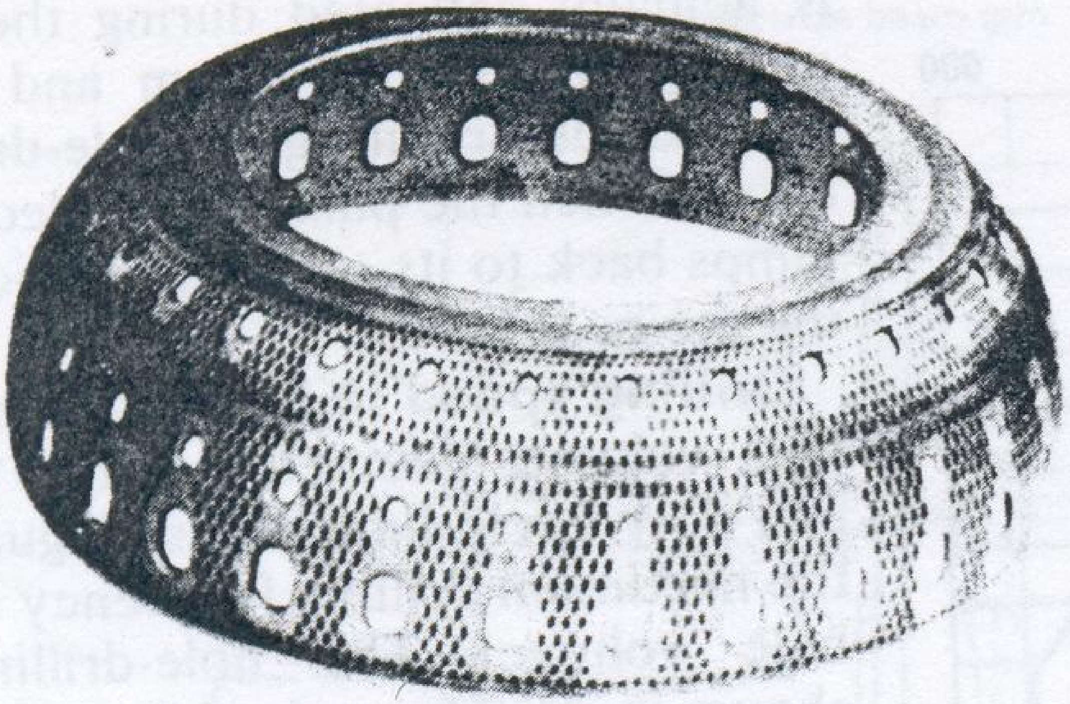


Fig. 8 Jet engine combustion chamber housing with electron beam machined holes. Courtesy of MG Industries/Steigerwald

Dome material: chrome nickel cobalt molybdenum tungsten steel; wall thickness: 1.1mm; hole dia: 0.9mm;

3800 holes drilled in 60mins

Example of slots cut by EBM - 1

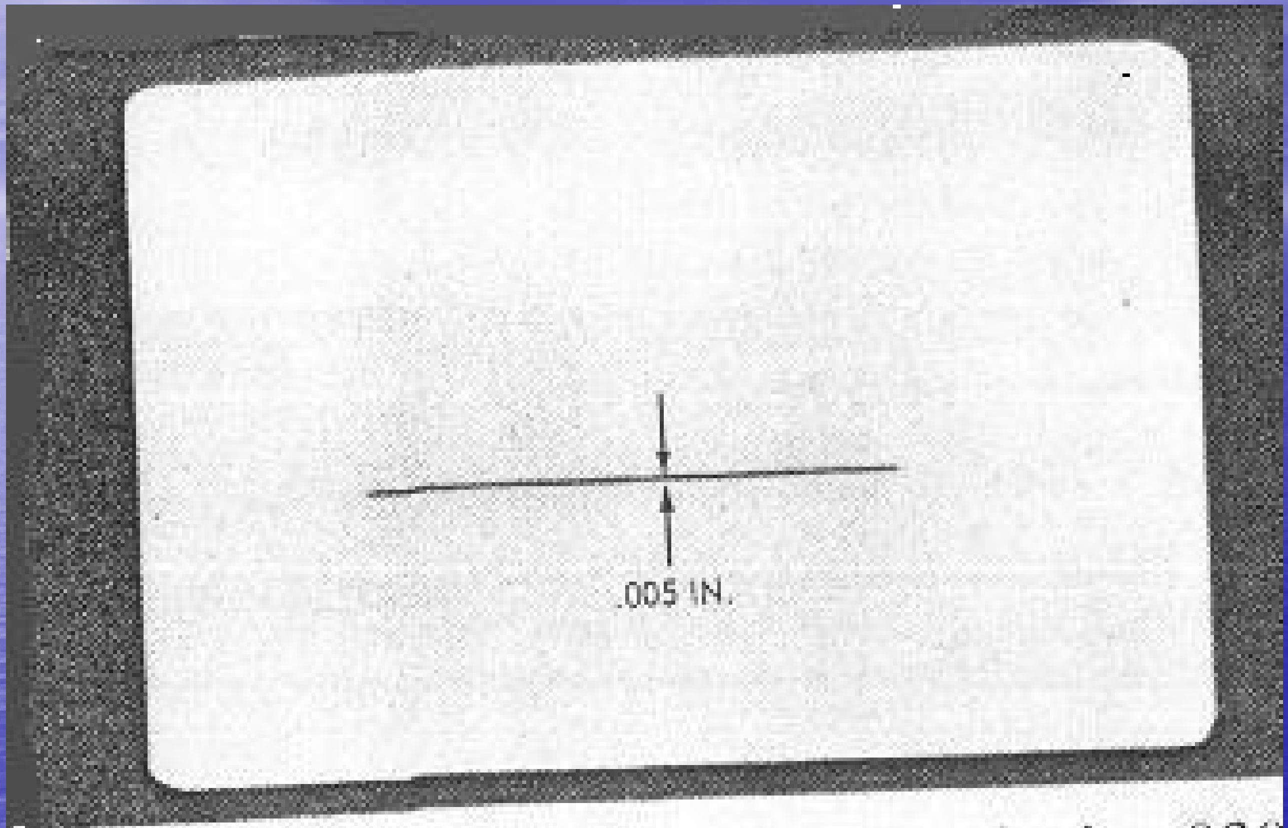


Fig. 6–9. Slot cut at 24 in/min in .030 in. aluminum oxide wafer. *(Courtesy: Hamilton Standard, Division of United Aircraft Corporation)*

Example of slots cut by EBM - 2

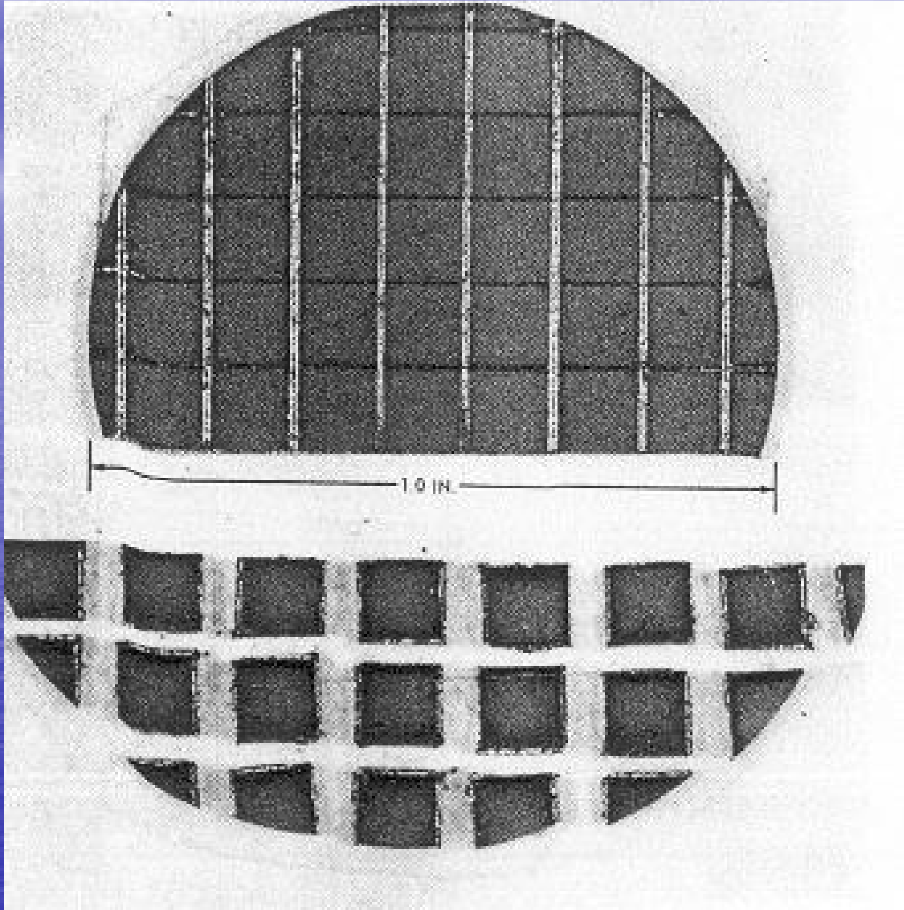


Fig. 6–10. Dicing of silicon chips for semiconductor industry. *(Courtesy, Hamilton Standard, Division of United Aircraft Corporation)*

Example of slots cut by EBM - 3

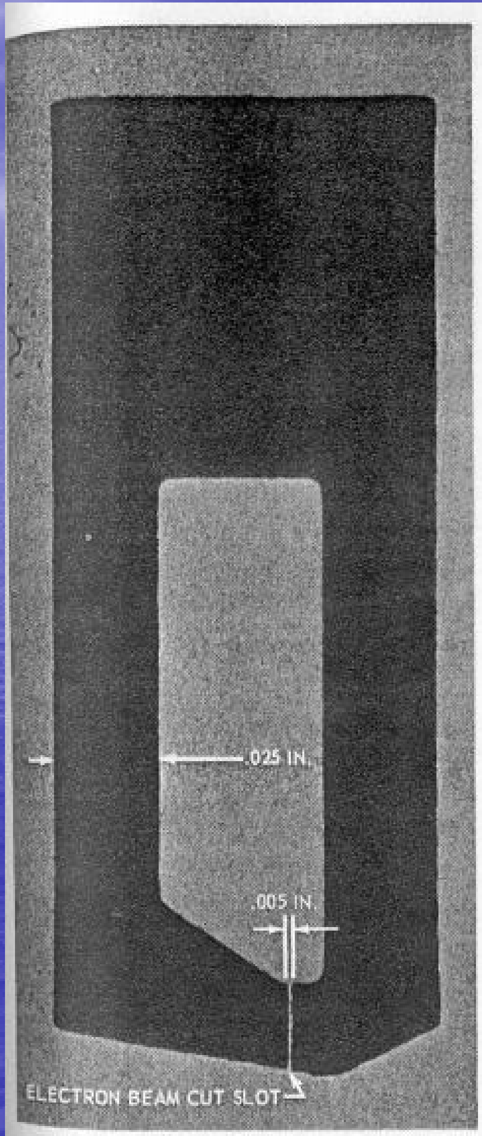


Fig. 6–11. Ferrite memory core (.005 in. thick). *(Courtesy, Hamilton Standard, Division of United Aircraft Corporation)*

Examples of EBM drilling - 1

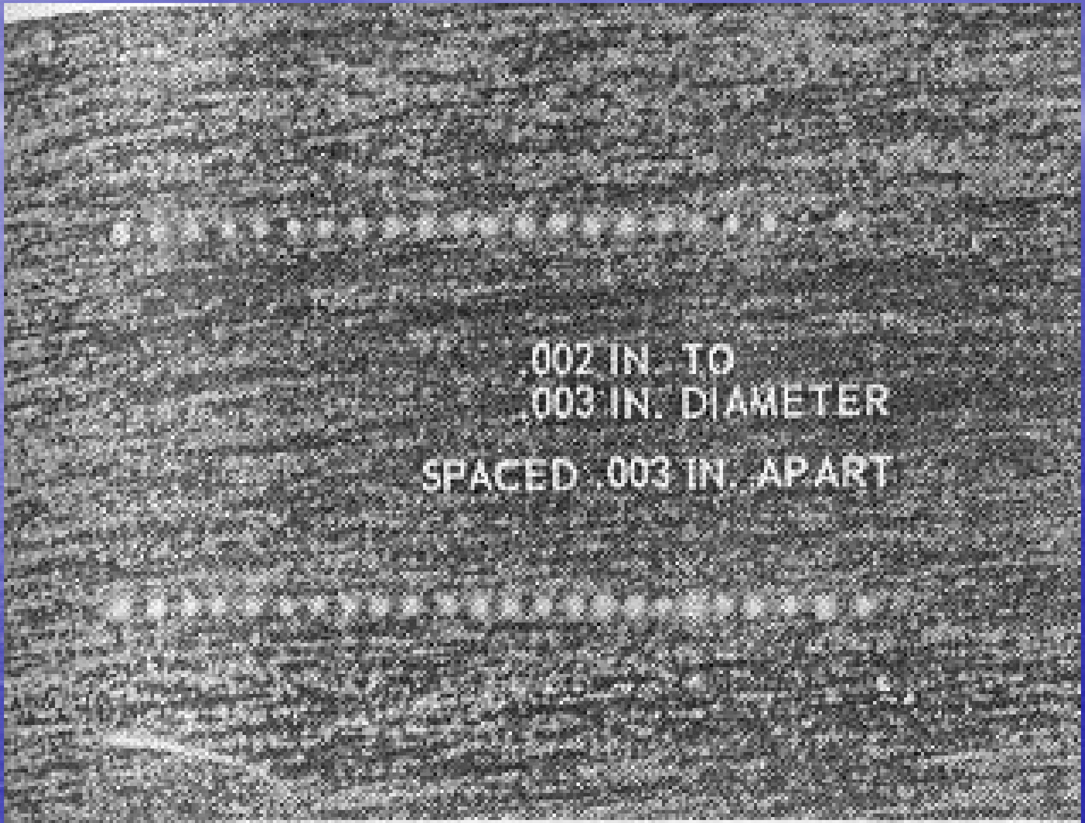


Fig. 6–5. EBM drilling of .010 in. thick molybdenum. *(Courtesy, Hamilton Standard, Division of United Aircraft Corporation)*

Examples of EBM drilling - 2

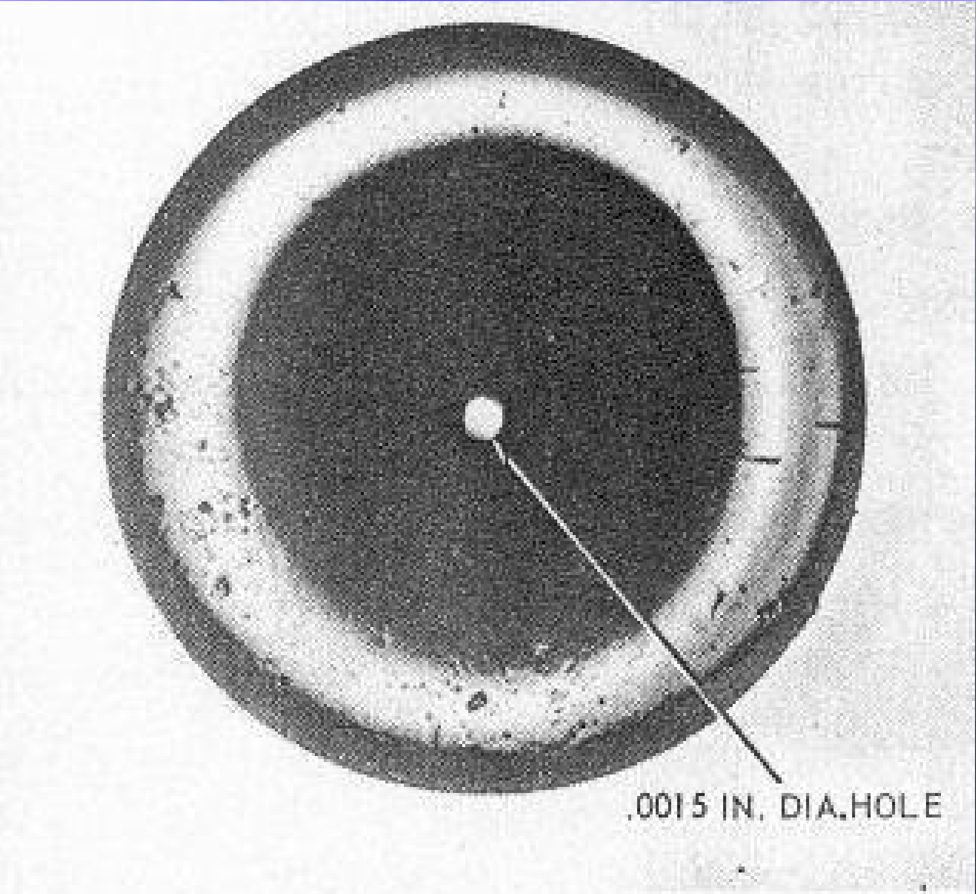


Fig. 6–6. Synthetic sapphire jewel bearing (1.0 sec. cutting time). *(Courtesy, Hamilton Standard, Division of United Aircraft Corporation)*

Examples of EBM drilling - 3

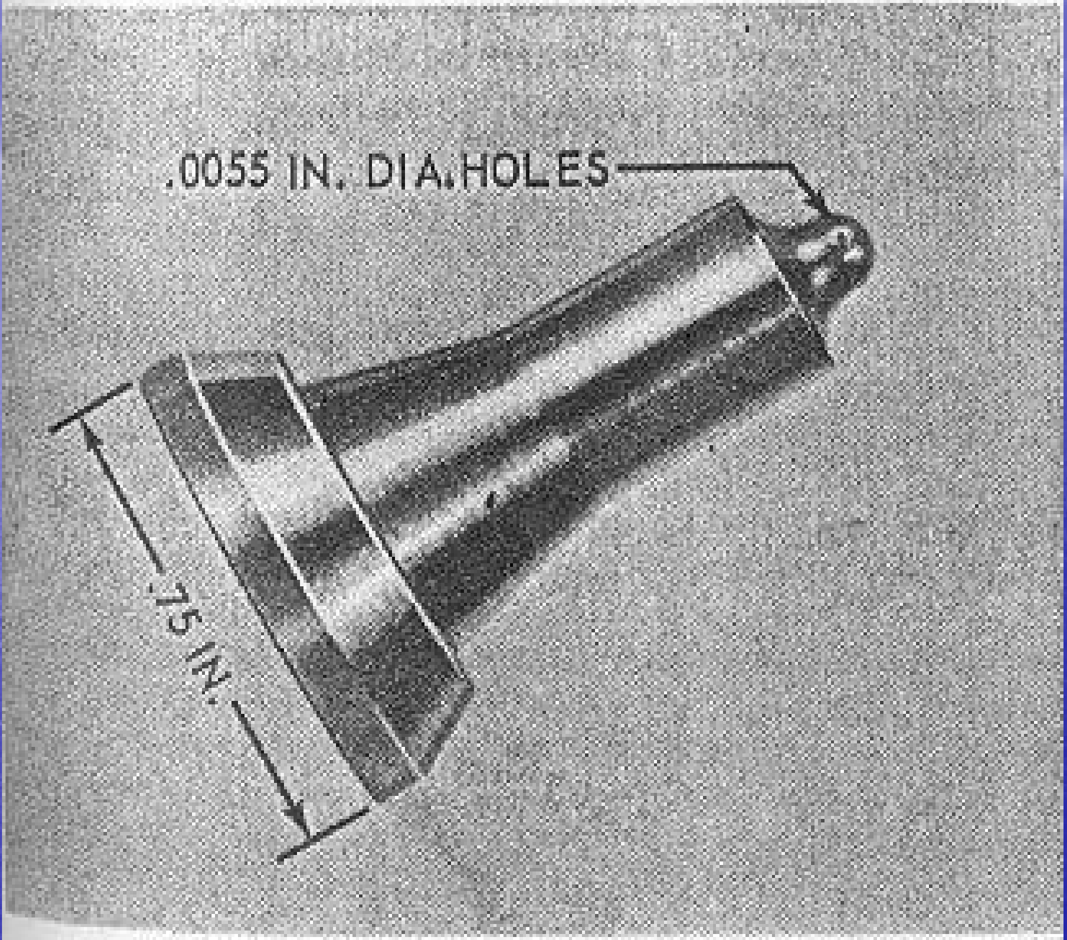


Fig. 6–7. Stainless steel injection nozzle. (*Courtesy, Hamilton Standard, Division of United Aircraft Corporation*)