LASER BEAM MACHINING (LBM)

Basic Introduction

LASER: “Light Amplification by Stimulated Emission of Radiation”.
LBM is machining process which uses pulsed LASER beams to cut metal.

- It is an unconventional / modern / non-traditional machining process.
- There is no direct / mechanical contact with the workpiece.
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Necessity:
High cost of cutting hard-to-machine materials by conventional machining processes. Reasons:

- low material removal rate
- short tool life
- Impossibility of even cutting some metals by the conventional machining.

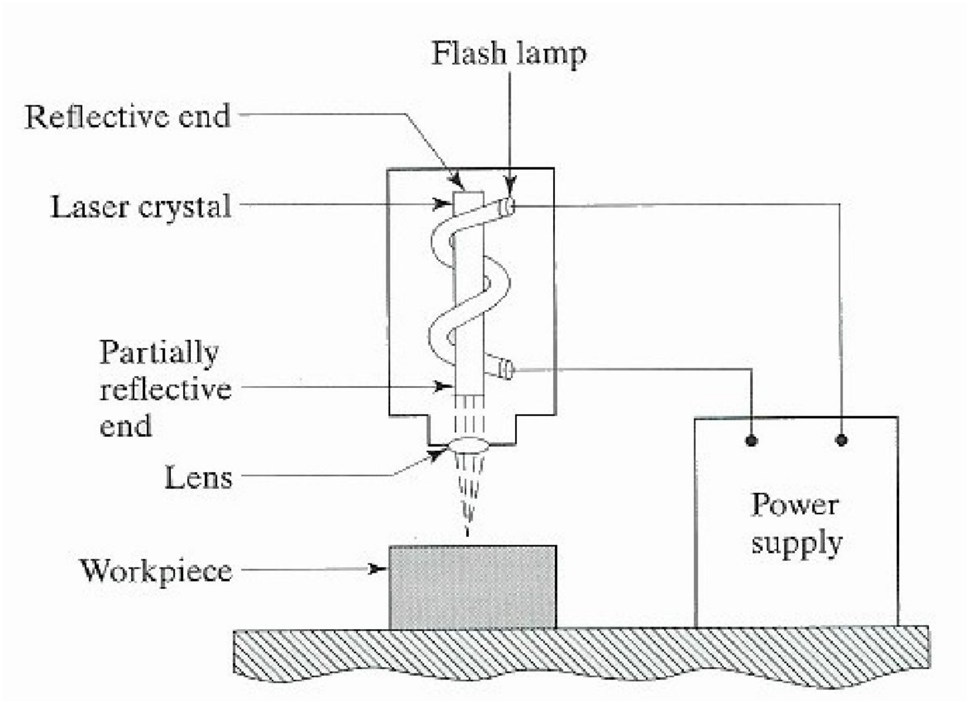
Types:

- Nd YAG - Neodymium doped Yttrium Aluminum Garnate
- Calcium Fluoride doped with neodymium ($Ca + F_2 + Nd$)
- Glass doped with rare earths
- Man made Ruby - $Al_2O_3 + 0.05\% Cr_2$
- CO_2 gas

Working principle

- LASER beams generated by suitably doped crystals contain very high energy density.
- This is focused on the work surface to remove metal by high temperature vapourisation or melting.
- This is removed by melt ejection, vaporization, or ablation mechanisms.

Equipment



Laser Tube & Lamp Assembly (main part). The following parts are fitted inside an enclosure, which carries good quality reflecting surfaces inside.

1. A LASER tube, consisting of crystal with suitable dope. Some examples & their properties:
    - Nd YAG - Neodymium doped Yttrium Aluminum Garnate
        - Chemical composition: $Y_3Al_5O_{12}$ + Nd
        - Solid State LASER
        - Allows fiber optic transmission
        - Power: upto 50 kW in pulsed mode
            - 10 kW continuous wave mode
    - Calcium Fluoride doped with neodymium ($Ca + F_2 + Nd$)
    - Glass doped with rare earths
    - Man made Ruby - $Al_2O_3 + 0.05\% Cr_2$
    - CO_2 gas
        - LASER lies in infrared region
        - Pulsed mode
        - Continuous mode: 25 kW power
2. A pair of reflectors, (one at each end of the tube)
3. A flash tube or lamp (filled with xenon)
4. An amplification source
5. A power supply unit
6. A cooling system

Cooling Mechanism

- A coolant is circulated in the laser tube assembly to avoid its overheating.
- It is essential as continuous operation produces a lot of heat
- Efficiency of the system decreases at high temperature.

Tool Feed Mechanism

- There is no tool used in the LBM process.
- Focusing laser beam at a pre-decided point in the workpiece serve the purpose of tool.
- As the requirement of being focused shifts during the operation, its focus point can also be shifted gradually & accordingly by moving the converging lense in a controlled manner.
- This movement of the converging lense is the tool feed mechanism in LBM process.

Design guidelines

- LASER works best on materials such as carbon steel or stainless steels.
- Metals such as aluminium & copper alloys are more difficult to cut due to their ability to reflect the light as well as absorb & conduct heat.
- This requires lasers that are more powerful.
- LBM is not a bulk material removal process.
- It is most suited to contour cutting, slitting & drilling small diameter deep holes
    - Length to diameter ratios of up to 50:1 are possible.
- There are special methods to create blind or stepped features, but they are less accurate.
- Sharp corners are possible, but radii should be provided for in the design.
- Some distortion may be caused in very thin parts.
- Maximum workpiece thickness:
    - mild steel: 25mm,
    - stainless steel: 13mm,
    - aluminium: 10mm.
- Localized thermal stresses & heat affected zones result.

Process Description

- LASER rod is excited by xenon filled flash lamp surrounding it.
- Both are enclosed in cylinder with highly reflective inner walls.
- The dopes present in LASER tube get excited.
- These atoms release photons while returning to normal state.
- Thus high energy beam is emitted in short pulses.
- The apparatus has reflective mirrors on the back side & side walls
- The partially reflective mirror on the bottom face allows emission of LASER beams.
- A converging lens is used to focus the LASER beam on the workpiece.
- Extremely high temperatures are generated which melt or evaporate the metal.
- This is removed by melt ejection, vaporization, or ablation mechanisms.

Process Variations

Process Parameters

- Nature of Beam light: Unidirectional, Coherent, Monochromatic, Short Pulse
- Total radiation of sun is 7 kW/cm^2
- Area: Can be focused on 1/100 mm^2
- Concentrated power intensity of 10^5 kW/cm^2

Laser rod of 3 joule unit is 6 cm in dia & 70 mm long

Performance Characteristics

Advantages

- Can even machine materials that are difficult or impossible to machine conventionally.
  - Very hard & abrasive material can be cut.
- No tool so all tool related problems like wear, cost, hardness, force etc eliminated
- Cost effective & flexible process.
- Gives high accuracy & precision.
- No cutting lubricants required.
- Can operate in any transparent environment or inert gas vacuum or liquids
- Material removal is independent of hardness. It depends on :
  - The optical properties of the laser
  - The optical & thermo physical properties of the material.
- Laser head need not be in close proximity
  - It can reach inaccessible locations
- Can machine heat shock sensitive materials. ex: ceramics
- heat is focused to a small area, so rest of the workpiece remains unaffected.
  - Narrow heat affected zone.
- Doesn't cut the work table if its made with reflective materials like Aluminium.
- Complex profiles & intricate shapes can be cut.

Disadvantages

- High capital investment & operating cost.
- Recommended only for some specific operations as production rate is very slow.
- Cannot be used comfortably for high heat conductivity & light reflecting materials.
- Skilled operators are required.
- System has low efficiency.

- Pulse repetition rate is lower than Electron Beam.
- Can't machine thermally conductive & reflective metals Al, Cu alloys.
- Irregular machined area due to off axis modes.
- Min dia depends on the divergence & hence the quality of laser material.
- Output energy can't be precisely controlled.

Applications

- Operations: Drilling, Cutting, Slitting, Slotting, Scribing
- Precision micro-machining on all microelectronic substrates such as ceramic, silicon, diamond, and graphite. Examples are given below
    - Ex: cutting, scribing & drilling all substrates,
    - trimming hybrid resistors,
    - patterning displays of glass or plastic
    - trace cutting on semiconductor wafers and chips.
- Material: any metal, ceramic or organic material
    - Must not disintegrate on melting
- Making complex profiles in thin & hard materials like integrated circuits & printed circuit boards (PCBS).
- Machining of mechanical components of watches.
- Smaller machining of very hard material parts.
- Used extensively in the electronic & automotive industries.
- It is used for very thin stocks.
- It is especially suited to making accurately placed holes.
- Fusion & welding of refractory materials.

Extra points:

The range of workpiece material that can be machined by LBM includes high hardness & strength materials like ceramics, glass to softer materials like plastics, rubber wood, etc.

A good workpiece material should possess high light energy absorption power, poor reflectivity, poor thermal conductivity, low specific heat, low melting point & low latent heat.

Minimum drilled hole diameter is about 0.025 mm.

In a lab test a beam focused on carbon produced 8000 Kelvin in 0.0005 seconds

Rays of a laser beam are monochromatic & parallel,

    it can be focused to a very small diameter

    can produce energy as high as 100 MW for a square millimeter of area.

Laser being coherent in nature has a specific property;

    if it is focused by conventional optical lenses can generate high power density.