Laser Beam Machining (LBM)

LASER BEAM MACHINING (LBM) is a method of cutting in which the work material is melted and vaporized by a narrow beam of intense monochromatic light (a laser beam). When the beam strikes the workpiece, the heat produced melts and vaporizes even the most refractory work materials.

Because of its high cost, laser beam machining is used only when no other method is satisfactory. It can make small holes in thin material and can produce small, precision cuts. By controlling the energy of the beam at lower levels, the laser method can also be used to weld fine wire.

Principle of the Laser. The word "laser" is an acronym for "light amplification by stimulated emission of radiation". This phenomenon can be explained in a simplified manner as follows: The absorption of a quantum of energy from a light source causes an orbital electron of an atom to jump to a higher energy level (an orbit farther from the nucleus of the atom). This electron in the "excited" atom may later drop back spontaneously to its original orbit, emitting the absorbed energy. The absorption of a second quantum of energy by an electron that is at the higher energy level results in the emission of two quanta of energy, and the electron returns to its ground state or original orbit.

The radiated energy has the same wave length as the stimulating energy and is in phase with it. By placing a laser rod in an optical cavity and using mirrors to focus the light on the laser rod, the energy is captured in the rod. The energy builds up in the rod while undergoing successive internal reflections, until a highly amplified light beam is emitted.

Machining

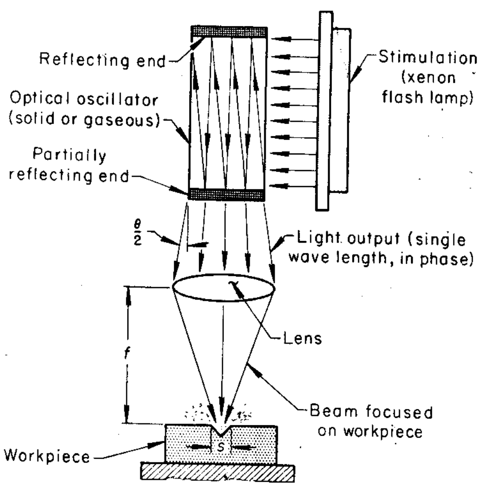
A typical setup for laser beam machining is shown schematically in Fig. 1. The stimulating light source usually is a linear arc-discharge lamp, such as a xenon flash lamp.

Laser Materials. Only the most powerful and reliable of the many different laser systems are suitable for use in machining operations. The most widely used laser materials are ruby and neodymium-in-glass.

The ruby laser material is crystalline aluminum oxide (corundum) that contains about 0.1% of chromic oxide. The laser rod can be a single crystal of synthetic ruby 1 cm in diameter by 10 cm long. The neodymium-in-glass material contains 2 to 6% neodymium and is fabricated into a rod similar to the ruby rod. The ends are finished as optical surfaces. Neodymium-in-glass is two to three times as efficient as ruby and is less sensitive to temperature changes. Both materials are nonconductors of electricity and hence are powered by a pulsed light flux, using a direct-current power supply and a bank of capacitors, instead of by direct electrical excitation.

Equipment and Procedure. Laser beam machining systems are operated at room temperature. In a typical operation, the capacitors are charged to 4000 volts and a 3000-joule pulse is then discharged in one millisecond through the pre-ionized xenon gas in the flash lamp.

The laser rod and the flash lamp are located at the foci of an elliptical polished aluminum reflector, so that nearly all radiation from the flash lamp is focused on the laser rod. The ends of the rod have reflective coatings. The coating on the exit end is partially reflective, to permit escape of the laser beam at 6 to 120 pulses per minute when the light has been amplified to a suitable intensity. The light emitted is an almost completely parallel beam, having a typical divergence angle (θ) of 10^{-2} to 10^{-4} radian. Because of its low divergence and monochromatic nature, the beam can be focused with a simple lens to obtain high power densities in small areas 1 to 6 in. from the lens. The relation between focal length, divergence angle, and diameter of machining spot is given with Fig. 1.



Machining spot diameter (s) = focal length of lens (f) times beam divergence (θ) in radians.

Fig. 1. Typical setup for laser beam machining

Additional equipment required for laser beam machining includes a triocular microscope for viewing the workpiece and for focusing the beam and a workholder to move the workpiece in three directions for accurate positioning at the focal point of the beam. The workpiece can be viewed from a distance by television. Water or air cooling is required, to dissipate the heat generated in the process.

Process Characteristics. A typical laser system can have an energy output of 20 joules with a pulse duration of one millisecond for a peak power of 20,000 watts. With a beam divergence of 0.002 radian, a power density of 7×10^9 watts per square inch is produced on a spot 0.002 in. in diameter at 1 in. from the lens. A power density of this magnitude can vaporize any known material.

Laser beam machining is very inefficient in energy consumption. The conversion of electrical energy to laser light energy for solid-state lenses has an efficiency in the range of 0.3 to 5%. There is a further loss of energy by partial reflection of the laser beam from the workpiece.

In machining, a short high-intensity pulse is desirable, to minimize the depth of the heat-damaged zone and to provide accurate dimensional control. The depth of heat damage is about 0.005 in.

Removal rate is only about 0.0004 cu in. per hour, the slowest of any machining process and less than 1/10 that of electron beam machining. The approximate amount of energy needed to remove a given amount of metal can be calculated from the specific heat and the heats of fusion and vaporization of the work material, and the estimated efficiency of energy conversion for the particular equipment. Relative power requirements for the removal of the same volume of various metals in a given time are:

Aluminum	1.0
Titanium	1.5
Iron	1.8
Molybdenum	2.2
Tungsten	2.9

Dimensional characteristics of holes produced by laser beam machining are:

Dimensional accuracy	±0.001 in.
Corner radii, minimum	0.010 in.
Taper per inch	0.050 in.

Taper is noticeable in holes deeper than 0.010 in.

Maintenance requirements are those for ordinary electronic and cooling equipment. Flash lamps require frequent replacement, their life being dependent primarily on the energy input and the current pulse shape. Commercial pulsed laser systems give a flash-lamp life of 10,000 to 100,000 pulses.

Cost. Both capital equipment cost and direct operating cost for laser beam machining are substantially higher than for conventional equipment and methods. Operating cost in cents per pulse is estimated as follows:

Flash lamp	2.0¢
Maintenance	0.2
Labor and overhead	0.5
Utilities	0.01
Depreciation	0.2 to 2.0
Total	2.9 to 4.7¢

This article is based primarily on information presented in Chapter 6 of "Non-Traditional Machining Processes", R. K. Springborn, editor, ASTME, Dearborn, Mich., 1967.

Advantages of LBM include:

1 Applicability to any known material
2 Absence of direct contact and large forces between tool and workpiece
3 Ability to machine through air, inert gas, vacuum, or optically transparent liquids or solids
4 Accuracy and ability to make very small holes and cuts
5 Suitability for cutting ceramic and other materials that are readily damaged by heat shock.

Disadvantages of LBM include:

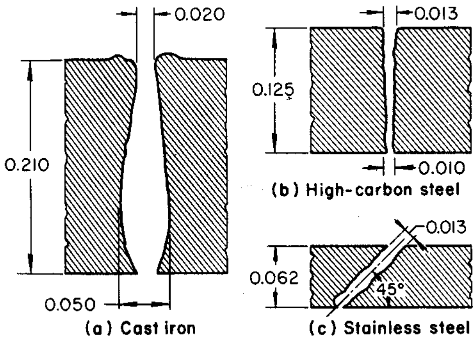
1 High capital and operating cost
2 Limited applicability (thin workpieces and removal of small amounts of material)
3 Slow production rate, because precise alignment is required
4 Nonuniformity of holes and cuts
5 Heat damage effects on workpieces
6 Need for skilled operators.

Applications. Laser beam machining is at present suitable only for exceptional applications that involve micro or high-precision operations difficult to perform by other methods. Although LBM can be applied to various metals, major use has been on ceramics. It is suitable for producing holes up to ⅛-in. diam in thicknesses up to ½ in.

Typical applications include drilling holes in tungsten, brass and ceramic, as described in the following tabulation. Less than one millisecond was required for drilling each of these holes.

Material	Thickness	Diameter
Tungsten	0.020 in.	0.020 in.
Brass	0.010	0.250
Ceramic	0.010	0.050

The characteristics of holes drilled in metals are illustrated in Fig. 2. The typical shape of a hole made in a single pulse is shown in Fig. 2(a); this air-flow hole did not require a uniform cross section but only a minimum diameter. A more uniform contour can be obtained with multiple pulses at lower energy level, as shown in Fig. 2(b). Figure 2(c) shows a 45° hole that takes advantage of the absence both of direct contact and of substantial forces between tool and work to avoid drift, curvature or mislocation.



(a) Irregularly shaped hole produced with a single pulse of 146 joules in 5 milliseconds. (b) Hole with 12-to-1 depth-to-diameter ratio drilled with multiple pulses. (c) Hole drilled at 45° angle with four pulses of 2.2 joules each.

Fig. 2. Holes drilled by laser beams

Laser beam machining has been used to drill a matrix of 100 holes spaced on 0.080-in. centers in 0.078-in.-thick zirconia. These 0.005-in.-diam holes were drilled by this method only after ultrasonic, abrasive jet, and electron beam techniques had failed to hold tolerances or had caused cracking.

Gas Laser. The CO_2-N_2 laser provides a high, continuous power output and a conversion efficiency greater than 13% (potentially above 20%), and is the most promising gas laser. Low power density of gas units is compensated for by a continuous output, lower cost and greater convenience. The infrared gas laser beam (wave length, 10.6 microns) is focused by mirrors instead of lenses, because most lens materials absorb radiation of this wave length.