An Intelligent Knowledge Based System for CO_2 Laser Beam Machining for Optimization of Design and Manufacturing

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Abstract: This paper addresses the concept of CO_2 Laser beam machining (LBM) and development of intelligent knowledge base system (IKBS) for CO_2 LBM. Feature based design is used for acquiring design specification. For optimization of laser beam machining computer based concurrent engineering environment is used. The IKBS is linked to feature base cad system. The IKBS is also linked to material database which holds attributes of more than 50 types of materials. It is also linked to Laser database which holds attributes of 3 types of laser machine. IKBS is also linked to Laser machine variables and parameters. For each design feature, IKBS provides information such as machining cycle time and cost and machining rate. By changing machine parameters, we can optimize machining cycle time and cost and cutting rate. The IKBS can be used as an advisory system for designers and manufacturing engineers. It can also be used as a teaching program for new CO_2 laser operators in computer based concurrent engineering environment**.**

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1   INTRODUCTION

The introduction is divided into three paragraphs. The first paragraph is about laser definition. The second paragraph is about importance of Laser beam machining. And the third paragraph is about new work. Photons are replacing electrons as the favorite tool in modern industry. Light is used for everything from eye surgery to telephone technology and materials processing. Photons are applied in an increasing number of topics addressed by this ISEM 14. An important property of light is that it has no volume, photons have no charge, so when concentrated into a very small space, they do not repulse each other like what the negative charged electrons do. This is an important property especial for ultrashort machining. Light moves through space as a wave, but when it encounters matter it behaves like a particle of energy, a photon. Not all photons have the same amount of energy.

The visible part of the spectrum contains wavelengths from 400 to 750 nm. Radiation below 400 nm includes the harmful frequencies of UV and X-rays, while above 750 nm the invisible infrared, microwave and radio frequencies are included. The energy of photons is $E=h\nu$. For the visible 500 nm wavelength this is 4×10^{-19} J or 2.5 eV per photon, which is not enough to break the chemical bonds in the material, which requires 3–10 eV. This can be solved in the laser materials processing in different ways. The first solution is simply heating the material by absorption of laser energy, which is a thermal or pyrolytic process. Secondly higher energy photons (UV) can be used with photon energies of 3–7 eV, which is used to break the chemical bonds directly (especially plastics). This is a photolytic process.

For metals even more energy is required (up to five times, the sublimation energy of about 4 eV for most metals). The third option is using lasers that deliver so many photons on a time that electrons are hit by several photons simultaneously. Absorption of multi-photons has the same result as single high energetic photons. In this case the photon energy, thus the wavelength, is less important because energy is transferred by multi-photons simultaneously [1]. Laser beam machining (LBM) is a thermal energy based machining process in which the material is removed by (i) melting, (ii) vaporization, and (iii) chemical degradation (chemical bonds are broken which causes the materials to degrade). When a high energy density laser beam is focused on work surface the thermal energy is absorbed which heats and transforms the work volume into a molten, vaporized or chemically changed state that can easily be removed by flow of high pressure assist gas jet. Since last five decades laser beams are being used in various industries.

Nowadays CO_2 Laser beam machining (LBM) is widely used in manufacturing. LBM is thermal energy based non-contact type advance machining process which can be applied for almost whole range of materials. Laser beam is focused for melting and vaporizing the unwanted material from the parent material. Laser light differs from ordinary light because it has the photons of same frequency, wavelength and phase. Thus, unlike ordinary lights, laser beams are high directional, have high power density and better focusing characteristics. In recent years the researchers have explored the number of ways to improve the quality of cutting, drilling and micromachining of different materials using CO_2 lasers. LBM is suitable for making parts with geometrically complex profile cutting and making miniature holes in sheet metal.

In recent years, researchers have explored a number of ways to improve the LBM process performance [2]. Laser (light amplification by stimulated emission of radiation) is a coherent and amplified beam of electromagnetic radiation. The key element in making a practical laser is the light amplification achieved by stimulated emission due to the incident photons of high energy. Laser light differs from ordinary light because it has the photons of the same frequency, wavelength and phase. Thus, unlike ordinary lights, laser beams are high directional, have high power density and better focusing characteristics [2]. Laser beam machining (LBM) is a thermal energy based machining process in which the material is removed by (i) melting, (ii) vaporization, and (iii) chemical degradation (chemical bonds are broken which causes the materials to degrade).

This paragraph is about importance of Laser beam machining. When a high energy density laser beam is focused on work surface, the thermal energy is absorbed which heats and transforms the work volume into a molten, vaporized or chemically changed state that can easily be removed by flow of high pressure assist gas jet. These unique characteristics of laser beam are useful in processing of materials. Planck in 1900 has given the concept of quanta and in 1920 it was well accepted that apart from wavelike characteristics of light, it also shows particle nature while interacting with matters and exchange energy in the form of photons [2]. By varying the powder composition, material properties can be changed continuously during the build-up. In this way, products made from graded materials are obtained. As well in laser welding and in laser cladding, CO_2-lasers are used because of their high power, better efficiency and good beam quality. The question that how short enough is can also be approached from the viewpoint of the applications.

Chen and Liu [3] compared different pulse widths and concluded that shorter pulses produce better quality but

at higher cost. For different materials, pulse length are: for metals 1 *ps,* for ceramics 10 *ps,* and for plastics 1 *ns*. Since, especially for glass and plastics, the material can be more or less transparent, for certain wavelengths this is just a rough indication. Detailed information is given by Bosman [4]. In general we will consider pulses shorter than 1ps as the ultrashort. Experiments at Lawrence Livermore however, show higher yields of 50 nm/pulse at F=4 J/cm^2 up to 350 nm/pulse at F=14 J/cm^2 which is the saturation limit according to Semak [5].

Ohmura et al. [6], [7], [8] and [9] have simulated the interaction and ablation behavior of aluminum, copper and silicon at 266 nm wavelength. The optical penetration depth was 7, 12 and 5 nm, respectively. By using different pulse generation techniques [10] the pulse duration, pulse energy and reproducibility can be modified over wide ranges. The mechanism for generating laser pulses lies in the nature of the active laser medium and the corresponding lifetimes of the atomic energy levels by using different pulse generation techniques [10].

This paragraph is about quality and new work. Two important parameters of LBM, which decide the quality of machining, are cut width/hole diameter and taper formation. The energy is stored in the laser material during pumping in the form of excited atoms and then released in a single, short burst. This is done by changing the optical quality of the laser cavity. The quality factor Q is defined as the ratio of the energy stored in the cavity to the energy loss per cycle. During pumping the high reflectivity (HR), mirror is effectively removed from the system preventing laser emission and a large amount of energy is stored in the active medium.

When the HR mirror is returned to proper alignment most of the stored energy emerges in a single short pulse [11]. While Q-switching can be used to generate pulses with high intensities in the ns-range, mode-locking is used to generate ultrashort laser pulses with pulse duration in the ps- to fs-range. Pulses in the ps-range were generated for the first time by passive mode-locking of a ruby laser shortly after its discovery by Mocker in the mid-1960s [12]. Passive mode-locking is based on the same principle as the active mode-locking, which is a temporal modulation of the resonator losses. In contrast to active mode-locking, the laser system itself determines the point in time at which the losses are at their minimum [13]. The passively Q-switched micro-lasers [14], [15] open new ways for micro-machining. A continuous wave diode laser of about 1 W is used to pump a laser material with a saturable absorber on the output window.

When this solid-state Q-switch reaches the threshold it becomes transparent within a nanosecond and a short pulse (0.3–1.5 ns) is delivered. Repetition rates are

between 2 and 50 kHz, pulse energy E_p (mJ), repetition rate v_{rep}, pulse duration t_p, and beam quality M^2. For the highest beam quality (M^2=1) beam is diffraction limited. The key properties are beam quality and output power as well as compact design. The combination of enhanced capabilities for tailoring the optical energy density with new laser systems and improved processing strategies using the advanced pico second lasers [16] leads to further improvement.

Yue et al., [17] have found the deeper holes with much smaller recast layer during ultrasonic-assisted laser drilling as compared with the laser drilling without ultrasonic aid. Laser-assisted seeding (a hybrid process of LBM and electro-less plating) process have proven to be superior than conventional electro-less plating during plating of blind micro-vias (micro-vertical interactions) of high aspect ratios in printed circuit boards (PCBs) [18].

In LAECM, the laser radiation accelerates the electrochemical dissolution and localizes the area of machining by few microns size which enables the better accuracy and productivity [19] De Silva et al., [20] have found that LAECM of aluminum alloy and stainless steel have improved the MRR by 54% and 33%, respectively, as compared with electro-chemical machining alone. They also claimed that LAECM has improved the geometrical accuracy by 38%. Li and Achara [21] have found that chemical-assisted laser machining (laser machining within a salt solution) significantly reduces the heat-affected zone and recast layer along with higher MRR as compared with laser machining in air.

Li et al., [22] have applied the LBM and EDM sequentially for micro-drilling of fuel injection nozzles. They initially applied the laser drilling to produce the micro-holes and then EDM was used for rimming the drilled micro-holes. They claimed that this hybrid approach has eliminated the recast layer and heat affected zones (HAZs) typically associated with laser drilling. They also claimed that the hybrid process enabled 70% reduction in drilling time as compared with EDM drilling. Electro-chemical or chemical etching processes are combined with laser beam for localized etching to enable selective material removal. The use of LAE has improved the etched quality and etching rate of super-elastic micro-gripper prepared by cutting of nickel–titanium alloy [23].

This paper addresses the concept of CO_2 LBM and developing an intelligent knowledge based system for laser beam machining. Feature based design is used to acquire design specification. Computer based concurrent engineering environment is used to optimize laser beam machining. The IKBS is linked to material data base which holds attributes of more than 50 types of materials. It also is linked to Laser data base which hold attributes of 3 types of lasers. The IKBS system is

also linked to Laser machine data base which hold Laser machine parameters. For each design feature, IKBS provides information needed for design and manufacturing optimization such as machining cycle time and cost and cutting rate. The IKBS can be used as an advisory system for designers and manufacturing engineers.   In figure 1 schematic of CO_2 laser beam cutting system is demonstrated.

2 CO_2 LASER APPLICATION AND IT'S PARAMETERS

LBM has wide applications in the field of automobile sectors, aircraft industry, electronic industry, civil structures, nuclear sector and house appliances. Stainless steel, a distinguishable engineering material used in automobiles and house appliances, is ideally suitable for laser beam cutting [24], [25], Advanced high strength steels (AHSS) machined by laser beam have applications in car industry and boiler works [26]. Titanium alloy sheets used in aerospace industry to make forward compression section in jet engines are cut by lasers [27]. Aluminum alloys used in aeronautics are one of the most promising for laser machining implantation [30]. Also, aluminum alloy samples of slot antenna array can be directly fabricated on laser cutting system [31].
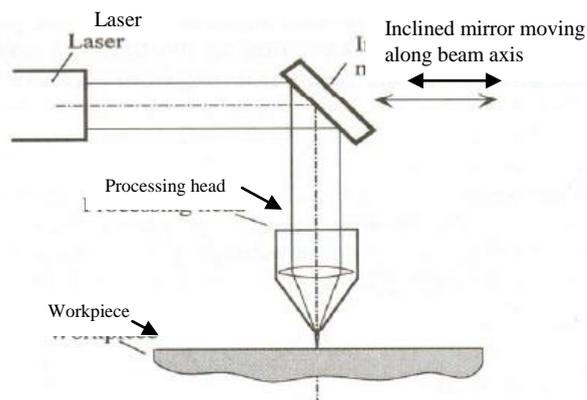

Fig. 1 Schematic CO_2 laser beam cutting system

LBM is the most suitable and widely used process to machine nickel base super alloys, an important aerospace material [34]. Smaller pieces of lace fabric (nylon 66) for lingerie are separated from the main web by CO_2 laser cutting [35]. In the past few years, CO_2 laser cutting of poly-hydroxy-butyrate (PHB) was used in the manufacturing of small medical devices such as temporary stents, bone plates, patches, nails and screws [36]. LBM can cut intricate shapes and thick sections in these tiles [37]. Werner et al., [38] have recently proposed the application of CO_2 laser milling in

medical field for producing micro-cavities in bone and teeth tissues without damaging the soft tissues. Two important parameters of LBM, which decide the quality of machining are cut width/ hole diameter and taper formation. Due to converging–diverging shape of laser beam, tapers always exist on laser machined components but it can be minimized up to acceptable range. Smaller kerf width or hole diameter reduces the taper.

Chen [39] examined the kerf width for three different assist gases oxygen, nitrogen and argon at high pressure (up to 10 bar) and found that kerf width increases with increasing laser power and decreasing the cutting speed during CO_2 laser cutting of 3 mm thick mild steel sheet. He also observed that oxygen or air gives wider kerf, while use of inert gas gives the smallest kerf. Ghany et al., [24] have observed the same variation of kerf width with cutting speed, power and type of gas and pressure as above during experimental study of Nd: YAG laser cutting of 1.2 mm thick austenitic stainless steel sheet. They have also found that by increasing frequency the kerf width decreases. The same effect of laser power and cutting speed on kerf width during CO_2 laser cutting of steel sheets of different thicknesses was observed by other researchers also [40].

Refs. [41] and [42] also show the same variation of kerf width with laser power and cutting speed during CO_2 laser cutting of different fibre composites. Karatas et al., [43] found that the kerf width reduces to minimum when the focus setting is kept on the workpiece surface for thin sheets (1.5 mm) and inside the workpiece for thicker sheets (3.5 mm) during hot rolled and pickled (HSLA) steel cutting using CO_2 laser. CO_2 and Nd:YAG laser drilling of polyester foils and glass fibre reinforced epoxy laminates give larger hole diameter at increased laser power[44].

Surface roughness is an effective parameter representing the quality of machined surface. Ref. [24] shows that surface roughness value reduces on increasing cutting speed and frequency, and decreasing the laser power and gas pressure. Also nitrogen gives better surface finish than oxygen. In Ref. [39] surface roughness value was found to be reduced on increasing pressure in case of nitrogen and argon, but air gives poor surface beyond 6 bar pressure. Also, surface finish was better at higher speeds. Ref. [40] shows that the laser power and cutting speed have a major effect on surface roughness as well as striation (periodic lines appearing on the cut surface) frequency. They have shown that at optimum feed rate, the surface roughness is minimum and laser power has a small effect on surface roughness but no effect on striation frequency. Chen [45] has not found the good surface finish up to 6 bar pressure (of inert gas) during CO_2 laser cutting of 3 mm thick mild steel.

Recently, Li et al., [46] have proposed the specific cutting conditions for striation free laser cutting of 2 mm thick mild steel sheet, variation of surface roughness with laser power and feed rate (cutting speed) during CO_2 laser cutting of 1.27 mm steel sheet Micromachining of 0.5 mm thick. Laser cutting of thick (1–10 mm) alumina ceramic substrates through controlled fracture using two synchronized laser beams, focused Nd:YAG (for scribing the groove crack) and defocused CO_2 (to induce thermal stresses) show that surface finish obtained at 60 W laser power (for both Nd:YAG and CO_2) and 1 mm/s cutting speed was much better than conventional laser cutting [47].The surface roughness of thick ceramic tiles during CO_2 laser cutting is mainly affected by ratio of power to cutting speed, material composition and thickness, gas type and its pressure [37].

Use of nitrogen assist gas and lesser power intensities reduce the surface roughness [41]. Pulsed mode CO_2 laser cutting gives better surface finish than CW mode [42]. The change in metallurgical characteristics of laser machined work parts is mainly governed by HAZ. Therefore, it is required to minimize the HAZ during LBM by controlling various factors. Decreasing power and increasing feed rate generally led to a decrease in HAZ [40].Wang et al. [85] also found the same effect of power and cutting speed on HAZ during CO_2 laser cutting of coated sheet steels. They also observed that increased oxygen pressure increases the HAZ. The micro-structural study of CO_2 laser machined aluminum alloy shows that HAZ increases as the depth of hole drilling increases [30].

Low material thickness and pulse energy gives smaller HAZ while pulse frequency has no significant effect on HAZ for laser cutting of thick sheets of nickel base super alloy [34]. Researchers have also studied the mechanical properties of laser machined work parts and found that thermal damages and crack formation affect the strength of materials. Zhang et al. [48] have found that the mean value of flexural strength reduced to 40% of original material after laser cut. Also, laser micromachining of silicon wafers shows that breaking limit after laser cutting is reduced [49].

3   SYMBOLS, AND ABBREVIATIONS

Laser	light amplification by stimulated emission of radiation
$E=h\nu$	energy of photons
E_p	pulse energy
K	beam quality factor
t_p	pulse duration
HEZ	heat affected zones
CW	continuous wave laser power
M^2	times diffraction limit factor (beam quality factor, $KM12=$)
D	beam diameter at the optic
fd	focused beam diameter
z	depth of focus
f	focal length
F	focal length divided by the beam diameter at the optic
p	plane of polarization
nm	nano meter
pm	pico meter
c	cutting direction
CW	continuous wave laser power
NA	Numerical Aperture
BPP	Beam Parameter Product (beam quality factor, $\pi\lambda 2MBPP=$)
CO_2	Carbon dioxide

4   ADVANTAGES OF CO_2 LASER BEAM MACHINING

Among various advanced machining processes, CO_2 laser beam machining (LBM) is one of the most widespread applications of lasers and a well-established and effective method of cutting a wide range of materials, mainly metals. LBM has several advantages over conventional methods. Firstly, as non-contact process, LBM it well suited for cutting advanced engineering materials such as difficult to cut materials, brittle materials, electric and nonelectric conductors, and soft and thin materials. Secondly, LBM is a thermal process and materials with favorable thermal properties can be successfully processed regardless of their mechanical properties. Thirdly, LBM is a flexible process.

Other advantages include narrow kerf width (minimum material lost), straight cut edges, low roughness of cut surfaces, minimum metallurgical and surface distortions, easy integration with computer numerically controlled (CNC) machines for cutting complex profiles. Sheet-metal cutting is the single largest, in terms of sales, global industrial laser application. CO2 lasers dominate this application due to their good-quality beam combined to high output power. It is estimated that more than 40,000 cutting machines using CO2 lasers have been installed worldwide. The laser cutting is one of the largest applications of lasers in metal working industry. It is based on the precise plate cutting by focused laser beam. Laser beam is a new universal cutting tool able to cut almost all known materials.

Other advantage of CO2 laser beam machining are numerous, namely, a narrow cut, minimal area subjected to heat, a proper cut profile, smooth and flat edges, minimal deformation of a workpiece, the possibility of applying high cutting speed, intricate

profile manufacture and fast adaptation to changes in manufacturing programs. For most engineering applications, the laser can be regarded as a device for producing a finely controllable energy beam, which, in contact with a material, generates considerable heat. The heat energy is supplied by a laser beam. The laser beam permits tool-free machining with active heat energy. The energy of light contained in the laser radiation is absorbed by the work piece and transformed into thermal energy. Laser beam is becoming a very important engineering tool for cutting. Laser cutting, especially of mild steel, is rather well introduced than new attractive process for thin sheet cutting. It is one of the most important applications for industrial lasers. Laser cutting is one of the important applications of LBM. It finds wide application in various manufacturing industries due to its high speed, quick setup, low waste, precision of operation and low cost.

5   INTELLIGENT KNOWLEDGE BASED SYSTEM FOR CO_2 LBM

An expert system is an interactive intelligent program with an expert-like performance for solving a particular type of problem using knowledge base, inference engine and user interface. In this paper the following step has been used:

5.1. IKBS for CO_2 LBM has been developed in a computer based CE environment, the third version of an expert system shell (NEXPERT), based on object-oriented techniques (OOT). A Hewlett Packard (HP) workstation was used in development of the IKBS. A geometric specification of design feature, and material type of the workpiece and its thickness is sent for manufacturability evaluation at the various stages in its design. Within the manufacturability procedure, the machining time and cost of producing part are estimated.

The labour and depreciation cost of CO_2 LBM for each selected design feature specification is estimated. Also various machining parameters are suggested.

5.2. The material specification are described in terms of its thickness, width and it's melting point etc. The attributes of different material types for CO_2 LBM, and different type of CO_2 LBM machine are stored in working memory or data-bases.

5.3. The IKBS can retrieve information from working memory and advise the designer on the appropriate choice of material, for workpiece, and type of machine.

5.4. The ES also contains information related to good practice rules for CO_2 LBM and, CO_2 LBM process capabilities, and constraints.

5.5. For the present IKBS, knowledge has been gathered from literature and talking with expert and experimental results on CO_2 LBM.

5.6. For each selected design feature, undergoing evaluation for its manufacturability by CO_2 LBM, the cost of the machine cycle is estimated from those costs for CO_2 LBM machine depreciation, labour, and machining cost.

5.7. Machine cycle time is also a key factor, which depends for example on setting-up of CO_2 LBM loading and unloading of work-piece, inspection of component, and general maintenance.

5.8. Assessment of the manufacturability of a workpiece material, usually from machining cycle time and cost, is established automatically by the IKBS.

5.9. This IKBS can advise on the manufacturing of each work piece material. From this information, the process variables can be selected that best balances between the required qualities against efficiency of manufacturing. Input, output, constraint, and features library, databases and parameters of IKBS CO_2 LBM are demonstrated in Fig. 2. A flow chart of IKBS CO_2 LBM is presented in Fig. 3.
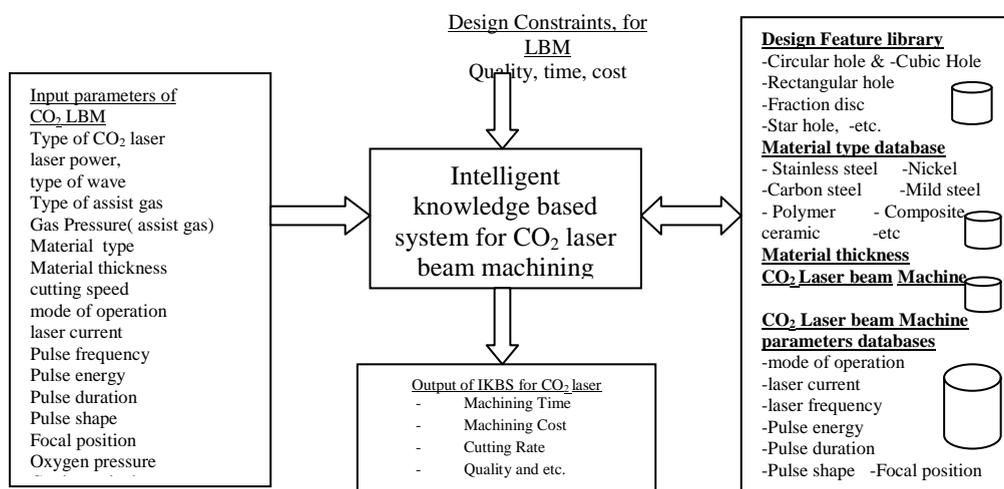

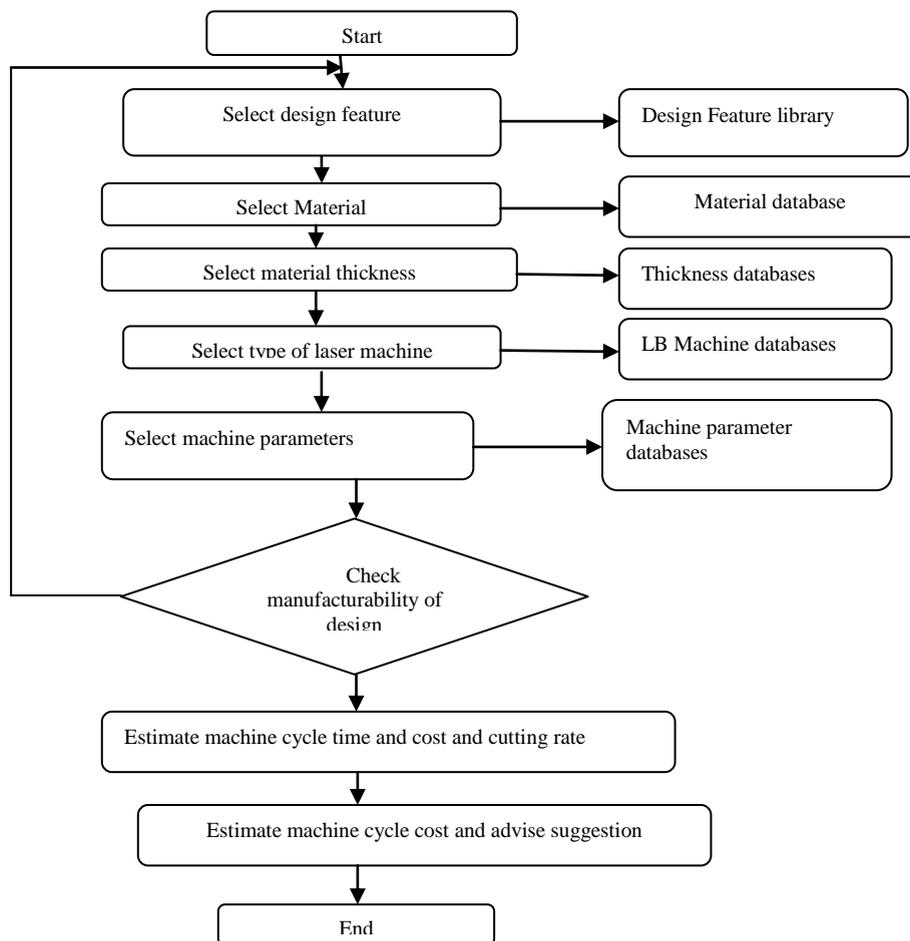**Fig. 2**   Input, output and databases of IKBS CO_2 LBM

Fig. 3   Flowchart of CO2 laser beam machining

6   ARCHITECTURE OF IKBS FOR CO_2 LBM

The IKBS contains expertise gathered from both experiment and general knowledge about CO_2 LBM that can be provided to designers and manufacturing engineers. . A flow chart of IKBS CO_2 LBM is presented in figure 3 from which the following modules are noted:

6.1. Material (workpiece) library: The material (workpiece) library contains 50 different material types for work-piece which interactively is acquired by the IKBS for CO_2 LBM. Each of which can be produced by CO_2 LBM machine.

6.2. CO_2 LBM machine characteristics: Information is contained on six different machine types of CO_2 LBM machines and their capital cost.

6.3. Machining cycle time and cost module: The knowledge base provides estimates of cycle time and costs for each selected design feature based on the selected material type, and CO_2 LBM process conditions such as on-time, off-time, and current.

6.4. Manufacturability: The manufacturability is assessed by consideration of the workpiece specification, the CO_2 LBM production rate, efficiency and its effectiveness of the machine used in their production.

7   EXPERIMENTAL VERIFICATION OF IKBS FOR CO_2 LBM

These experiments have been carried out in CNC CO_2 LBM machine. Two different types of environment are used to compare the results of experimental CNC CO_2 LBM and results of The IKBS. Experimental CNC CO_2 laser cutting is used in this paper. The CNCCO$_2$ laser beam system is that a beam is directed down to a part for cutting. The part sits on a computer controlled platform which moves the piece around the stationary laser beam. Cutting is achieved by passing the beam through a focusing lens. A focused beam exits through the bottom of a cutting head nozzle. Gas, such as

oxygen, is fed into the side of the chamber below the focusing lens. This gas exits the nozzle along with the beam and the laser beam/oxygen combination serves to vaporize the steel for cutting. Usually purchasing the laser was the easy part; many other systems are required to be on-line in order to achieve useful laser beam machining. The basic elements of a CNC CO_2 laser cutting are demonstrated in figure 4. Comprehensive components of a CNC CO_2 laser cutting are the following:

Fig. 4   The CNC CO_2 laser cutting

Electrical: Two 110V AC 20 amp lines were run to operate ancillary equipment, or a 220V AC 20 amp line services the laser power supply, a 220V AC 20 amp line services the chiller outside of my house, and another 110 V AC 15 amp line runs room lighting.

Ventilation: A ventilation system was installed in the work area. This was required to remove fumes and reduce smoke that will contaminate the optics inside the beam delivery system. The laser has the capability to cut a number of different materials like metal, wood, plastic and etc. Ventilation is essential to remove the fumes produced by these materials

Gas Lines: The laser cutting system could use either oxygen or nitrogen depending on the cutting application. This required that a couple tanks were installed and ended up mounting the tanks up off the wall. Gas line is shown in figure 5.

DC Power Supply: The supply produces 48VDC at 50 amps and requires 220VAC input. The power supply was used for air-cooled and digitally controlled. Power supply is shone in figure 5.

Control systems: CO_2 laser uses connector that supplies control and input modulation signals to the RF amplifier and supplies status information from the amplifier. This allows monitoring of the temperature,

duty cycle, and supports digital control of the overall power output of the laser.

Support Arm: The laser head needs to be suspended about 48 inches away from the nearest wall. Another design criteria was that it has to be able to change the height of the laser along the z-axis of CNC.

Fig. 5   The Power supply and Gas line

Support Arm: The laser head needs to be suspended about 48 inches away from the nearest wall. Another design criteria was that it has to be able to change the height of the laser along the z-axis. A CAD drawing was put together, and I bought a pile of channel iron, angle iron, and flat stock then went to work with my chop saw. Note the lag bolts attaching the angle iron to wall and floor. The IKBS for CO_2 LBM for as described above was compared with experimental CO_2 LBM. Results are presented in Table 1.

The Laser Head: The system is based on the Coherent G-100, an RF excited sealed industrial C02 pulsed laser. It consists of 100 watt laser resonator and solid state RF amplifier integrated into an all aluminum enclosure. The RF amplifier provides pulsed RF power to the laser to ionize the CO2 gas mixture in the tube. A modulation signal applied to the laser head controls the output pulse width and period. The amplifier produces 3000 watts of RF power. The head of CO2 laser head is demonstrated in figure 6.

Fig. 6   The CO_2 laser head

The result of the intelligent knowledge based system (IKBS) shows machining time and cost for IKBS is about 10 percent less than the experimental one. For example experimental shows machining time, for

rectangular hole is 0.18 minute, But the IKBS estimation is 0.165 min. Machining cost, for experimental rectangular hole is 0.4 US dollar. Also machining time for experimental circular hole is 0.34 minute, but for IKBS is 0.31 min. Experimental machining cost is 0.34 dollar, but for IKBS is about 0.31 dollar. The experimental circular hole is 0.4 US dollar which is approximately 10 percent less than experimental one. In table 2 machining time and cost of various type of design feature are estimated by IKBS for CO_2 LBM.

8 CONCLUSION

Laser beam machining (LBM) is a thermal energy based machining process in which the material is removed by (i) melting, (ii) vaporization, and (iii) chemical degradation (chemical bonds are broken which causes the materials to degrade). When a high energy density laser beam is focused on work surface, the thermal energy is absorbed which heats and transforms the work volume into a molten, vaporized or chemically changed state that can easily be removed by flow of high pressure assist gas jet. This paper has described concept of CO_2 LBM and its parameters effect on laser beam machining and developed an IKBS for CO_2 LBM process.

The IKBS described above was compared with experimental CO_2 LBM. Results are presented in table 1. The result of the expert system shows machining time and cost for IKBS is about 10 percent less than the experimental one. For example experimental shows machining time, for rectangular hole is 1 minute, But the IKBS estimation is 0.89 min. Machining cost, for rectangular hole for experimental is 0.4 UK pound, but for IKBS is 0.36 UK pound, which is approximately 10 percent less than experimental one. Future directions of CO_2 LBM research are very important for researchers. Most of the literature shows that researchers have concentrated on a single quality characteristic as objective during optimization of CO_2 LBM. Optimum value of process parameters for one quality characteristic may deteriorate other quality characteristics and hence the overall quality. No literature is available on multi-objective optimization of CO_2 LBM process and present authors found it as the main direction of future research.

Table 1 The Comparison of experimental CO_2 LBM and IKBS for CO_2 LBM for cubic and rectangular hole and laser cutting for stainless steel material, pulse frequency 100 HZ, length of canon 50 mm

Type of design feature	Type of material	Feature dimension (mm)	Assisted gas	Laser power (W)	Procedure	Laser machining time (min)	Laser Machining cost US$	Cutting velocity mm/min
Rectangular hole	Carbon steel	width 100, length 150 thick 3mm	Oxygen	800	Experimental	0.18	0.4	2700
Circular hole	Stainless steel	diameter 100mm thick 3mm	Nitrogen	1500	Experimental	0.34	0.25	900
Laser cutting	Titanium	length 400 thick1.5mm	Argon	1500	Experimental	0.188	0.12	3400
Rectangular hole	Carbon steel	width 100, length 150 thick 3mm	Oxygen	800	IKBS for CO_2 LBM	0.165	0.36	3000
Circular hole	Stainless steel	diameter 100mm thick 3mm	Nitrogen	1500	IKBS for CO_2 LBM	0.31	0.23	1000
Laser cutting	Titanium	length 25 thick1.5mm	Argon	1500	IKBS for CO_2 LBM	0.17	0.11	3800

Also, various experimental tools used for optimization (such as Taguchi method and RSM) can be integrated together to incorporate the advantages of both simultaneously. From above discussion it can be concluded that:

- Apart from cutting and drilling, CO_2 LBM is also suitable for precise machining of micro-parts and the micro-holes of very small diameters.
- CO_2 LB cutting process is characterized by large number of process parameters that determines

efficiency, economy and quality of whole process and hence, researchers have tried to optimize the process through experiment based, analytical, and AI based modeling and optimization techniques for finding optimal and cutting with multi-objective, and with hybrid approach are non-existent in the literature.

- Laser Beam Machining process is a powerful machining method for cutting complex profiles and drilling holes in wide range of workpiece materials. However, the main disadvantage of this process is low energy efficiency from production rate point of

view and converging diverging shape of beam profile from quality and accuracy point of view.

- The performance of laser beam machining mainly depends on laser parameters (e.g. laser power, wavelength, mode of operation), material parameters (e.g. type, thickness) and process parameters (e.g. feed rate, focal plane position, frequency, energy, pulse duration, assist gas type and pressure). The important performance characteristics of interest for CO_2 LBM study are HAZ, kerf or hole taper, surface roughness, recast layer, dross adherence and formation of micro-cracks.

Table 2   The results of IKBS 0f CO_2 LBM for different design feature in carbon steel material

Type of feature	Feature descriptions (mm)	Type of material	Laser power (W)	Assisted gas	Cutting velocity mm/min	Laser machining time (min)	Laser Machining cost US $
Circular hole	dia 100 thick0.25	Carbon steel	80	Oxygen	1270	0.25	0.15
Triangular hole	Edge100 Thick6.4	Carbon steel	1200	Oxygen	2000	0.15	0.09
Rectangular hole	width 150, length 250 thick 0.75	Stainless steel	1200	Nitrogen	4500	0.18	0.11
Cubic hole	width 100 thick 6	Stainless steel	900	Nitrogen	5000	0.08	0.05
Star hole 10 edge.	edge 100 thick 6.4	Stainless steel.	650	Oxygen	1000	1.0	0.6
Hexagonal hole	edge 150 thick1.5	Titanium	1500	Argon	3800	0.24	0.14

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