Available online at www.sciencedirect.com
SCIENCE DIRECT®
Optics & Laser Technology 37 (2005) 577–581
Optics & Laser Technology
www.elsevier.com/locate/optlastec

A generalized structure based on systemic principles of the characteristic variables of material laser processing

Adelina Han[a,b,*], Dinu Gubencu[b], Gianni Pillon[a]

[a]LTM Laboratory-EA 2976, Burgundy University-Chalon sur Saône, France
[b]Faculty of Mechanical Engineering, 'Politehnica' University of Timisoara, Romania

Received 11 June 2004; accepted 6 August 2004
Available online 23 November 2004

Abstract

The paper analyses the three main variables categories that are structurally characterizing the material laser processing: the influence factors, the process variables and the objective functions. These variables are divided in subsets determined by the system's structure, operating procedures and objectives of technological transformations.

Keywords: Laser processing; Systemic study; Independent variables; Objective functions

1. Introduction

The use of laser beams (LBs) as erosive agents [1] is due to the various properties of laser radiation, being determinate by the possibility of beam concentration on very small surfaces, having precisely defined geometrical shapes and sizes. Thus, it becomes possible to realize some local intensities and fluencies of the radiation greater than the threshold values, required for the activation and maintaining of some erosive processes in the irradiated material. Therefore, any technological action of LB processing represents a controlled transfer of energy, conditioned and intermediated by the LB incidence and, respectively, absorbance on the workpiece's (WP's) surface [1,2].

The character and the dynamics of the effects induced by laser radiation in the WP depend on the irradiated material proprieties, on the beam laser, as well as the interaction time. Hence, in accordce with the laser beam intensity and the interaction time, a group of technological processing methods was developed, such as heat treatment, welding or processes based on material removal [3–5]. A particular method is laser processing using material contribution (for example alloying, cladding), where purpose is the improvement of the surface layer's properties, by changing its chemical composition [6].

Material laser processing knew a large development due to its numerous offered advantages, for instance we reveal the absence of mechanically induced material damage and of tool wear, the possibility of the microprocessing, the automation possibilities and the flexibility that permits to perform various technological operations with the same laser processing system [1,3,7].

On the other hand, in case of some technological methods of materials processing, like welding, scribing, grooving, and surface treatment, conventional technologies are not efficient or even possible, but LB processing can assure the imposed requirements for increasing the quality of accomplished WPs and the production rate, and for minimizing production costs [5].

Obviously, material laser processing has also some disadvantages, like the appearance of the heat affected zone HAT, a relative low repeatability and reproduct-

*Corresponding author. Corresponding author. LTM Laboratory-EA 2976, Burgundy University-Chalon sur Saône, France.
E-mail addresses: adelina_han@iutchalon.u-bourgogne.fr (A. Han), gianni.pillon@iutchalon.u-bourgogne.fr (G. Pillon).

0030-3992/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.optlastec.2004.08.012

ibility of the obtained results for quality parameters, the impossibility of machining WPs having high thickness values, and expensive processing systems [3,7].

2. Independent variables and objective functions of material laser processing

Laser processing is difficult to control because of the nature and complexity of the phenomena and processes that are developing among the LB–WP interaction (absorption of the radiation, local heating, melting, vaporization, ablation, material ejection). In addition, as the majority of the technological systems, laser systems are complex (depending on many and very different influencing factors), diffuse (with significant interactions between the involved factors) and weakly arranged (having, at least, a partial stochastic behaviour) [8,9].

For the optimization or for the analytical and/or empirical identification of the laser processing, its systematic study is very useful. Considering laser processing as a technological action system (Fig. 1), this one can be structurally characterized by three main categories of variables [5,10–12]:

- independent (input) variables, representing factors which react on the system;
- process variables, deciding the process development, which are leading to technological transformations;
- dependent (output) variables, also called objective or response functions, representing technological and technical economic performance parameters of the process.

2.1. The input variables

The input variables set (Fig. 1A), acting for the process initiation to obtain technological transformations, may be divided in two categories:

- variables of the proper structure, quasi-inflexible for the adopted construction solution;
- operating variables, whose variation ranges are determined by the preceding quantities and which can be adjusted, rapidly, depending on the process-imposed requirements.

The first category includes qualitative factors as well as quantitative factors. The last ones from both mentioned categories are expressed by physical quantities, which are establishing dependence mathematical relations with the process and output variable values.

The input variables connected to the structure of the processing system, considering its subsystems, are separated into correlated subsets, as follows: the LB, WP, workpiece installing (WPI), cinematic control subsystem, assist gas (AG), and addition material AM [3–5,13].

Among the input variables associated to the LB, the most important are: power, temporal mode, wavelength, focal spot size, and spatial mode.

Generally, the highest continuous wave power is obtained from CO_2 laser, while Nd:YAG lasers provide the highest peak power for pulsed operation. The thermal properties determine the amount of laser power (or energy) required to melt and vaporize the material; this includes heat capacity, latent heat and heat of vaporization. On the other hand, a fraction of energy is transmitted to the surrounding material during processing. Thermal diffusivity is most important in transient operations, while thermal conductivity is more important in steady-state applications [2,3].

The temporal mode capability of a laser depends greatly on the lasing medium. Characteristically, solid lasers operate best in pulsed mode and at relatively lower powers in continuous mode. Gas lasers typically operate in a continuous mode with limited pulse capability [3,14]. The selection of a laser and an operating mode depends strongly on the desired machining operating. Pulsed operation is usually best for deep penetration processes (drilling, cutting). The concentration of energy in each pulse leads to a small percentage of energy lost through conduction into the WP or dissipation to the environment. Continuous power operation is used when high average power is required, especially on the heat treatments.

The wavelength is determined by the lasing medium too. The absorptivity of material depends on the wavelength of incident light, and thus certain lasers will be more suitable for the processing of different classes of materials [1,7]. For example, some metals such as aluminium and copper show low absorptivity at a CO_2 wavelength. They can be machined more effectively by using a Nd:YAG laser, whereby the copper and aluminium absorptivity values are much higher.

In material processing, irradiance (power per unit area) of the LB at the material surface is one of the prime importance [3]. Focusing a LB can generate irradiance great enough to melt or vaporize any material. The maximum irradiance is obtained at the focal point of lens, where the beam is at its smaller diameter. The location of this minimum diameter is called the focal spot, usually with a diameter of 0.2–0.4 mm.

The spatial mode represents the distribution of energy in the longitudinal and transversal section of the LB. The Gaussian spatial distribution (TEM_{00}) is usually considered the best for laser machining because the phase front is uniform and there is a smooth drop-off of irradiance from the beam centre. But there are some heat treatments which are necessary to

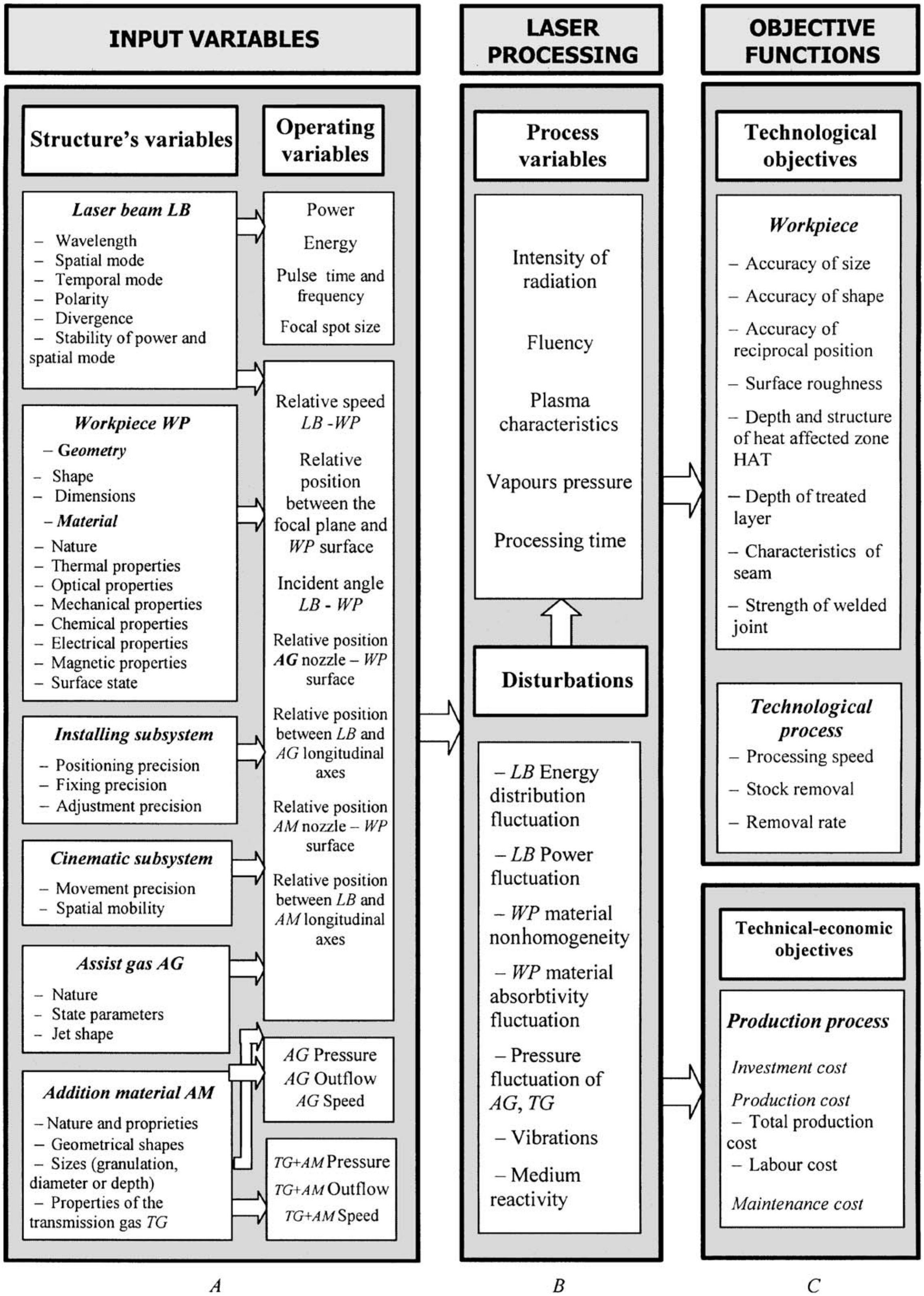

Fig. 1. Characteristic variables of material laser processing.

have a uniform repartition of the energy in the LB or, more than that, to transform the circular section to a square one. In this situation, it is recommended to use a higher-order mode beam or some adequate device for the division and the recombination of the LB [14,15].

Among the input variables related to the WP, the most important are the thermal and optical properties, mainly determined by the melt and vaporization temperature, diffusivity and thermal conduction, respectively by the absorbtivity of the WP material. Some materials can be opaque to one wavelength and partial or total transparent at another [1,3].

The nature and the state parameters of the AG have a high influence on the material removal processing, the gas directly participating sometimes to the sustenance and amplification of the erosive phenomena (oxygen cutting laser process) [7].

The AM, used in the cladding and the alloying treatment, must be compatible with the WP material. It has to assure an optimal dilution in the base material, for an optimal concentration and homogeneity of the alloyed layer [6].

2.2. The output variables

The finality of all the processing transformations is evaluated by both technological and technical-economic objective functions (Fig. 1C). The technological objectives characterize the effects induced in the WP by the technological transformation action (accuracy of the processed WP, surface quality), as well as the technological process (production rate). The technical-economic objectives are related to the production processes (investment, production and/or maintenance cost). Depending on the performed laser processing method, these technological objectives are different [10,11].

After the overall analysis of the material-manufacturing laser processes, which are presenting different technological transformation mechanisms, both objective functions that are common to all processes, and proper response functions for each laser technological method were identified (Fig. 2). Among the diverse processes belonging to the same method, there are similar influence factors and objective functions, in an overwhelming proportion.

Moreover, laser processing, based on the thermal degradation mechanisms due to the LB–WP interaction, induces a series of undesired transformations, characterized by output variables, common to laser manufacturing processes, such as the depth and the structure of the heat-affected zone HAT.

In case of material laser surface heat treatment, the main purposes followed are just to clean the surface or

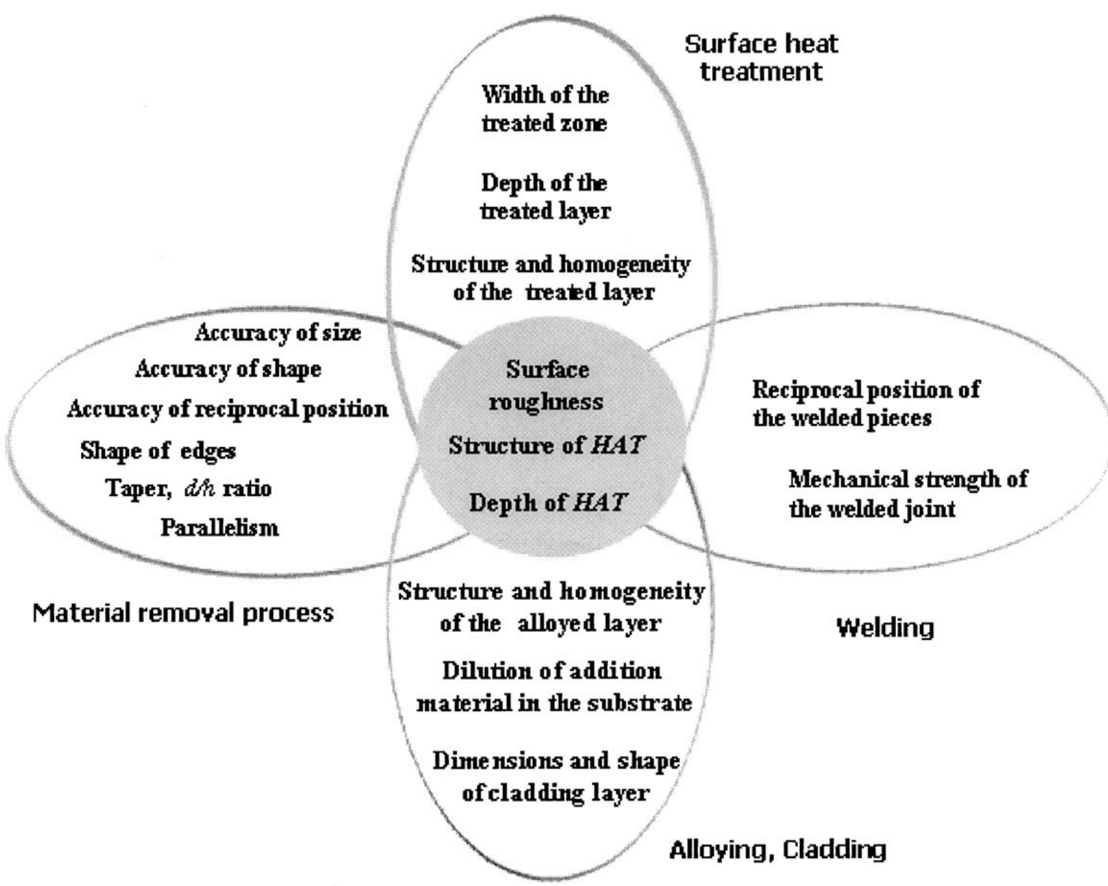

Fig. 2. Objective functions of the material laser processing.

to obtain a required structure and depth of the treated layer and/or a necessary surface roughness. In other applications, laser treatment is utilized in order to improve surface humectation properties.

The most important performance response functions that characterize laser manufacturing processes using material contribution (in gaseous or solid state) are the AM dilution in basic material, as well as the shape and the characteristics of the seam. In case of laser welding, the main objective is the mechanical strength of the welded joint.

In material removal processes, generally, the objectives are the accuracy of size, shape and reciprocal position as well as the surface finish (Fig. 2). For example, in laser drilling, the main technological objectives are the hole diameter accuracy, the hole taper and the hole roughness. Besides surface roughness, in laser cutting, the difference between the top and the bottom of the kerf width, and the shape of edges at the kerf corners are very important. For scribing and marking it is specific to increase the charring of the materials like polymers or wood to make the engraving more legible. In laser milling, dimensional accuracy is related particularly to the taper angle for each of the two grooves.

Because a certain transformation can be produced by different speeds and energy consumptions, therefore by different production costs depending on development conditions, technological indicators, that characterize the technological process, like production rate, as well as economic indicators, like manufacturing cost, are considered too (Fig. 1C). These are not representing machining purposes, but only decision criteria [11].

3. Conclusions

Knowing exactly these variable interdependences, we can react on the technological system for obtaining the required values of the technological and/or economic objective functions. Yet, the dependences cannot always be entirely known and mathematically quantized, because technological systems are complex, diffuse and unsettled. On the other hand, analytical modelling has a practical limited importance, due to the accepted simplifying hypotheses.

This presented systemic approach is useful especially for experimental modelling of laser processing. The final purpose is the optimization of some performance indicators shown in Fig. 1C or of some multi-objective functions defined by using these indicators, subject to specific constrains for different laser processing methods. Furthermore, this approach described above makes possible the material laser processing optimization by developing some high-performance laser systems, based on processing databases and knowledge bases, including the results and conclusions of scientific research, as well as industrial expertise.

References

[1] Nichici A. Prelucrarea prin eroziune in constructia de masini. Editura Facla: Timisoara; 1983.

[2] Von Allmen M. Laser-beam interactions with materials. Berlin: Springer; 1987.

[3] Chryssolouris G. Laser machining, theory and practice. New York: Springer; 1991.

[4] Charchan S. Guide to laser materials processing. Laser Institut of America; 1993.

[5] Han A. Stadiul actual al tehnologiilor laser de prelucrare a materialelor polimerice. PhD. rapport no. 1. Universitatea "Politehnica" Timisoara; 2002.

[6] Mordike BL. Surface treatement by laser. Laser de puissance et traitements de matériaux. Lausanne: Presses Polytechniques et Universitaires romandes; 1991.

[7] Cicala E. Optimizarea proceselor de taiere conturata cu laser a materialelor. PhD. thesis. Universitatea "Politehnica" Timisoara; 1997.

[8] Nichici A, Cicala E, Mee R. Prelucrarea datelor experimentale. UP Timisoara; 1996.

[9] Nichici A, Cicala E. Introduction in the strategy of materials laser cutting processes optimization. Laserap 4, Tome 2, Marquay; 2001.

[10] Gubencu D. Imbunatatirea performantelor sistemelor de control activ in procesele de rectificare, PhD thesis. Universitatea "Politehnica" Timisoara; 2001.

[11] Gubencu D. Systemic analysis of the active control grinding process. Revista de Tehnologii Neconventionale, vol. 1. Timisoara; 2001.

[12] Lungu M, Visan A. Studiul sistemic al proceselor care caracterizeaza prelucrarea prin eroziune electrochimica. CITN 6; 1993.

[13] Nichici A, Cicala E. Alegerea laserilor pentru prelucrarea materialelor. Simpozion Tehnologii novative prezent şi perspective. edicţia a II-a. Editura Tehnică, Bucureşti; 1997.

[14] Merlin J, Li JC, Manderscheid T, Renard C, Oliviera C. Transformation et caractérisation d' un faisceau laser CO_2 pour les applications en traitement de matériaux. Laser de puissance et traitements de matériaux. Presses Polytechniques et Universitaires romandes, Lausanne; 1991.

[15] Han, A. Posibilitati de optimizare a proceselor tehnologice de prelucrare cu laser. PhD rapport no. 2. Universitatea "Politehnica" Timisoara; 2003.