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THE OPPORTUNITIES TO USE LASER TECHNOLOGY IN AUTOMOTIVE AND AEROSPACE INDUSTRY

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Introduction

From the very start of laser era in the early 60th the numerous laser technology applications had been developed and implemented into different fields of industry the automotive and aerospace industries being among the first because of their most expansive, dynamic and fast accepting innovations nature.

Among these applications the most widespread are the following: drilling precise holes of small diameters; cutting slots and sheet metal sharing; hardening, surface alloying and cladding of cutting tools and components; welding; components marking and engraving; mechanical cutting intensified with laser radiation etc. High technologies based on laser beam use provide the processing productivity and product quality and reliability increase, save time and money in manufacturing, give other advantages to manufacturers in their fight with competitors in globalized economy.

Laser hole drilling

Laser hole drilling has great advantages in case when other alternative technologies are not able to provide very high productivity, the possibility to obtain holes with different shape in cross section or/and in longitudinal section especially in the range of small diameters (from few microns up to 1,0 –1,5 mm) with depth of up to few millimeters in different hard to machine materials. Deviations of hole diameter are usually in the range of 10 – 12% of nominal size.

One of good example of this technology application in automotive industry is laser drilling of precise holes in fuel nozzle for diesel engine. Eight holes of 250 microns in diameter with tolerance ± 10 microns in stainless component are usually obtained either by conventional drilling with super hard alloy drill or using electro discharge wire electrode machining. In first case the machining productivity and hole quality is very high but the drill tool life is too short because of often tool breakage. At electro discharge process the hole quality is excellent but the machining time is equal to 20–25 min and wire electrode wear is very high. In both cases it is practically impossible to get hole with varying shape.

At laser machining all 8 holes of quite high quality are pierced in less than 0,7 min. The hole shape may be obtained like Laval nozzle thus increasing the efficiency of fuel injection. Nd:YAG laser with pulse energy in the range 10 J had been used to perform this operation [1].

For aerospace industry there had been developed the laser industrial system for hole drilling in long (0,5–3 m) stainless tubes 15–40 mm in diameter with wall thickness 0,8 mm [2]. Such tubes are used as spraying collectors in the preventing fire systems and in the systems to prevent icing of Antonov Company aircrafts and some types of helicopters. The developed equipment has the focusing device moving along the long tube according to programme and tube itself may be turned around its axis to the necessary angle providing the required hole diameter – 0,8 mm (fig. 1).

Very prospective field for laser hole machining is manufacturing turbine blades for gas turbine engines both for automotive and especially for aerospace industry. To increase the blade life by preventing them from overheating and even burning the most critical in respect to temperature rise surfaces of such blades are usually perforated to pump through system of holes the cooling liquid. Laser perforation provides highly efficient technology for piercing shaped holes at curved surfaces in components made from hard to machine materials – heat resistant alloys.

Paper had been presented at the International Conference "Global Automotive Laser Applications" in the framework of "International School of Quantum Electronics" held at Erice-Sicily (Italy) on 1–7 August 2001 and is given here with some modification.

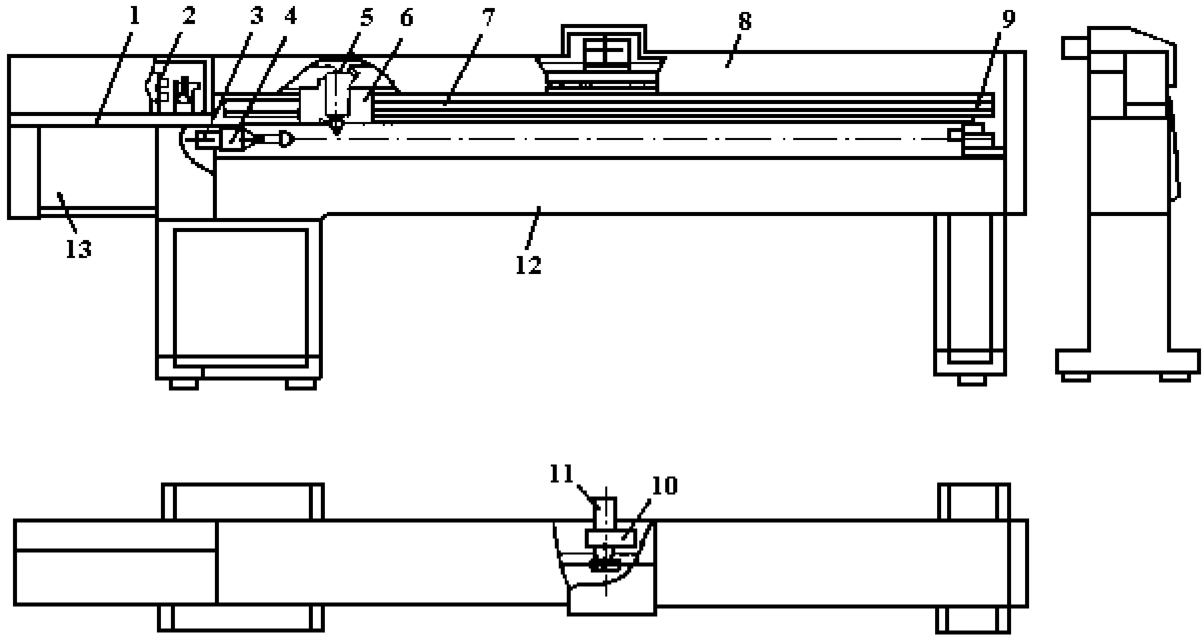


Fig. 1. Sketch of laser system for drilling holes in long tubes:
1 – arm; 2 – laser; 3 – step motor; 4 – redactor; 5 – focusing device; 6 – carriage; 7 – slides; 8 – housing, 9 – moving support; 10 – fulfilling mechanism; 11 – step motor; 12 – base; 13 – CNC block.

Recently designed types of turbine blades have the ceramic layer on the surface to improve temperature resistance of the blade. But such design leads to the additional problems in machining because no traditional technologies are possible to apply the only alternative being laser hole piercing.

To increase the efficiency of large hole drilling in thick materials the combined electro-laser process had been developed [3]. According to this technique the initial hole is pierced with few laser pulses in the component, which serves as a main electrode, and when the gap between this electrode and auxiliary electrode is ionized (because of formed plasma and erosion products) then the energy stored in capacitor is released (fig.2). The initiated in such way the powerful electrical discharge causes additional material erosion and as a result the hole diameter becomes larger making the shape of the hole itself more cylindrical. Thanks to intense molten material flow the hole surface topography is improved as well.

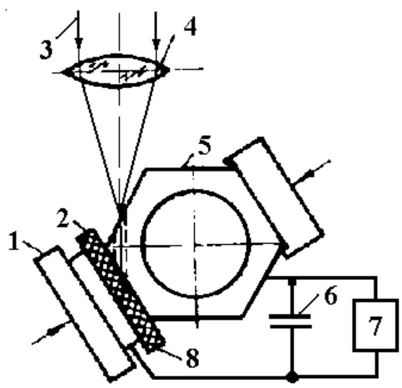


Fig. 2. Scheme of electro-laser hole piercing in nut:
1 – clamp; 2 – auxeliary electrode; 3 – laser beam; 4 – focusing lens; 5 – nut; 6 – capacitor; 7 – power supply; 8 – dielectric media.

Using the described technology the cylindrical holes on the sidewalls of nuts for reliable fixing them with the help of wire are drilled much more efficiently in comparison with other conventional methods.

Electro-laser hole piercing is good to use at stamp matrix manufacturing with wire EDM. The initial hole in a plate from super hard material to insert wire electrode is usually obtained using time consuming EDM with single wire electrode. Electro-laser technique allows shortening the procedure by factor 15–20.

Such preliminary holes may be obtained using the only laser piercing as well but for thick plates laser hole piercing will be more energy and time consuming process and the laser itself must be more powerful.

Laser cutting

Laser blank tailoring recently became wide spread technology in automotive and aerospace industry [4–5]. This technology has revolutionized the manufacturing process proposing many unique advantages for car body manufacturers. At the same time there are many still not so bright and wide spread cutting applications, which nevertheless may be of interest for advanced industry.

One of them concerns cutting of ceramic materials. For the last two decades the amount of components from ceramic materials used in car, aircrafts and missiles has increased drastically. The main advantage of such components – high heat, wear and corrosion resistance – is contradicting with the main technological characteristic – ability to be machined. The traditional methods of such materials machining are limited mainly by diamond wheel cutting and by ultrasonic machining. But cutting with diamond wheel is possible only when trajectory of material shearing is a straight line and ultrasonic machining needs specially designed complicated tool [6]. The quality of laser ceramic cutting with pulsed laser beam is improved significantly when processing is performed using the additional scanning (linear or circular) of the beam (fig. 3).

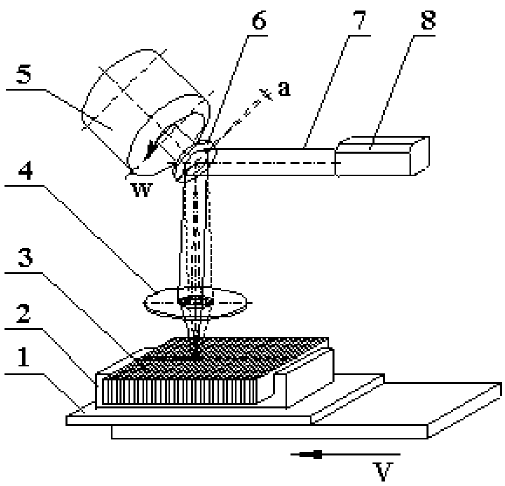
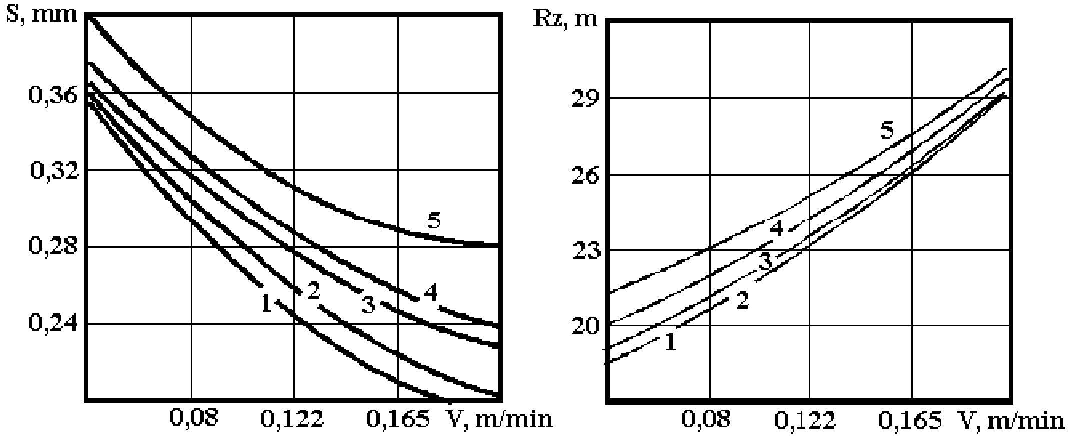


Fig. 3. Scheme of laser cutting with additional beam scanning:
1 – table; 2 – clamping device; 3 – component; 4 – focusing lens;
5 – motor; 6 – scanning mirror; 7 – beam; 8 – laser.

Such combined technique of cutting (beam movement + additional scanning) appears to be effective for shearing thin silicon plates (0,4–0,6 mm thick) for solar elements. As it is known these elements are now in great demand as an alternative source of energy both in automotive and aerospace industries. Usually for shearing silicone plates only diamond wheel cutting and ultrasonic cutting could be used but both these technologies have too much drawbacks. So the laser is the most acceptable alternative.

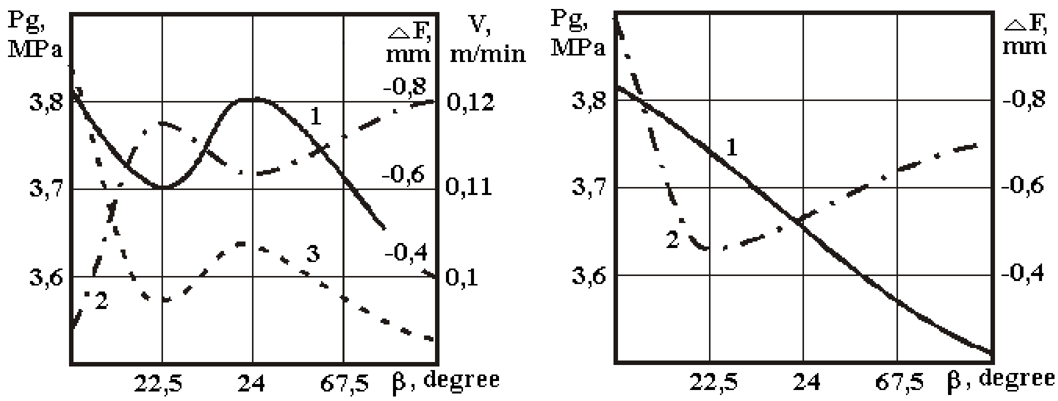
Besides the achieved increase in quality and productivity laser cutting provides 30% decrease of the heat-affected zone (HAZ). The latter brings the increase of the “useful” area of solar elements and correspondingly provides the increase of its efficiency at 5–6% in comparison with standard technology of solar elements shearing [7].

One of the key problems for automotive and aerospace industry is how to decrease the product weight with simultaneous increase of its reliability (strength and wear resistance). Partial but prospective solution of this problem is wide implementation of composite materials, based on carbon, glass, organic plastics and hybrid composites, based on combination of metals like aluminum-boron (Al-B). The more dissimilar the comprising metals (elements) the more difficult to machine such composites with traditional cutting tools because of high tool wear and losses of diamonds. For aluminum-boron composite there is one more specificity at it’s cutting – the machining quality is critical to the direction of cutting in respect to direction of reinforcing boron filaments location. Laser cutting is found to be the highly efficient technology for machining such materials. Cutting speed is affecting significantly both cut width and surface roughness (fig. 4) and the best results for these both parameters (narrowest cut width and lowest roughness) are obtained when the direction of speed vector of sample movement and direction of boron filaments location coincide, e.g. at β=0° (β – angle between speed vector and direction of filaments) [8]. It is possible to minimize the influence of anisotropy of composite Al-B thermal properties on cut quality by controlling the following processing parameters: cutting speed *V*, pressure of supporting gas Pg, beam defocusing ΔF (fig. 5).



a *b*

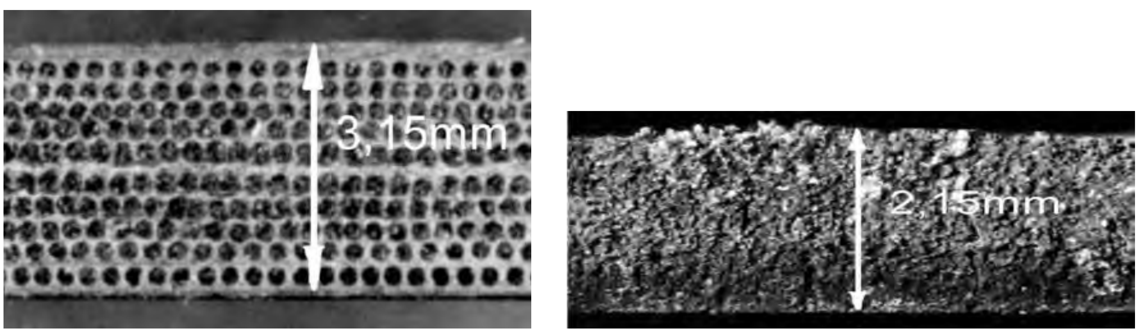
Fig. 4. Dependencies of cut width S (a) and cut surface roughness Rz (b) of cutting speed V for different angles β between speed vector of sample movement and direction of boron filament location at laser cutting of hybrid composite Al-B 2.15 mm thick with pulse laser radiation (mean power Pm=300W, working gas – Are, Pg=3 Atm, ΔF=0 mm) 1 – β=0°; 2 – β = 22,5°; 3 – β=45°; 4 – β=67,5°; 5 – β=90°.



a *b*

Fig. 5. The relation of pressure 1, beam defocusing 2, cutting speed 3 and an angle β between speed vector of sample movement and direction of reinforcing filaments at laser cutting of hybrid composite Al-B 2,15 mm thick with max quality (a) and productivity (b).

Fig. 6 demonstrates the cross section of the hybrid composite Al-B and the appearance of the cut side wall obtained after laser cutting.



a *b*

Fig. 6. Cross section (a) of hybrid composite Al-B and exterior (b) of a laser machined cut (side wall).

In some cases laser cutting process can be integrated in manufacturing of different components by traditional machining methods. In manufacturing special shafts for micro electro motors for executive mechanisms laser had implemented into automated metal cutting equipment to cut off ready shafts (fig. 7). Due to noncontact processing in this case the cut off operation of relatively long and nonrigid shaft was possible instead of mechanical cut off which would need additional end clamping of the shaft.

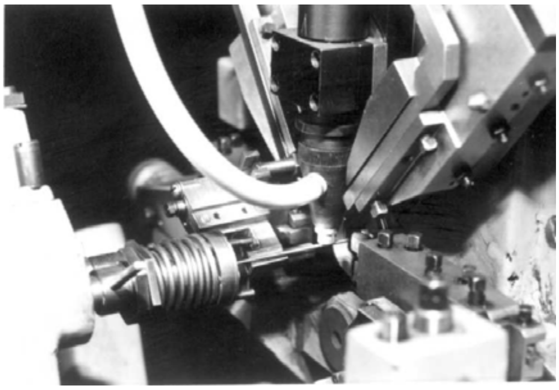


Fig. 7. Laser processing of shaft of micro electric motors.

Laser hardening

Laser hardening technology is widely used now both for improving the quality of new components of different machines at their manufacturing and to restore worn off components. Quite wide field of application as well is laser hardening of working parts of different cutting tools, stamping elements and instruments.

Treatment	Hardness H_{μ}, MPa
Without heat treatment	850
Heat treated	1000
LA (Mn)	2180
LA (Ni)	2200
LA (Fe)	3500

For automotive industry the use of aluminum and its alloys is becoming the very important issue. But some properties (for example, low hardness and heat strength) of these very prospective for car builder's materials are limiting their application. Using traditional laser hardening (transformation hardening) it is possible to increase material hardness in irradiated zone by factor 1,5–3. Our research had shown as well that laser surface alloying of aluminum alloys might change significantly the working characteristics of the treated components. Thus at laser alloying (LA) of technical aluminum Al 25 with Mn, Ni and Fe there is the large increase of hardness in comparison with untreated alloy and even with heat treated alloy (table 1). And this high level of hardness is preserved even at keeping of irradiated samples for long time at high temperature. The maximum level of heat strength increase had been observed at aluminum laser surface alloying with Fe (fig. 8).

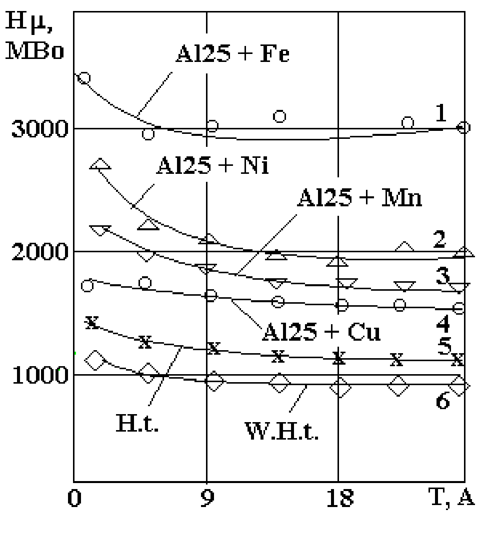


Fig. 8. The influence of laser surface alloying on Al 25 alloy's heat resistance.

From 1–2 elements composition for local surface alloying in the past for laser cladding the multielements composition are developed now. The most wide spread powders are produced on nickel base. The main drawbacks of such powders are high price, gripping of cladded layer at dry friction and formation of significant tensile stresses.

New compositions have been developed at LTRI based on Fe-B-C-alloy. Due to iron base the tensile stresses formed in cladded layer are usually lower than in case of Ni-based composition. Such compositions are much cheaper than Ni-based or Co-based alloys, they are non toxic, they provide the cladded layer hardness of high level and the adhesion of new alloys is good because of cladded and matrix material similarity.

The technology had been developed to increase wear resistance of camshafts and crankshafts of car engines at their manufacturing using CO2 laser. This innovation brought the long life increase by factor 2–2,5. For worn off components of this type the restoration technology based on laser cladding had been developed. Tribology tests for restored camshaft revealed that for laser cladded cam the wear rate is about 2,5 times less than that for traditionally quenched cam.

In automotive and aerospace industry there are many components of fuel supply systems which need the preservation of their dimensional parameters for long time. One of such example is fuel cut off stock (fig. 9), the working surfaces of which had to have high level of wear resistance. Laser transformation hardening of stock edges had been implemented which increased the life of this component by factor 2.

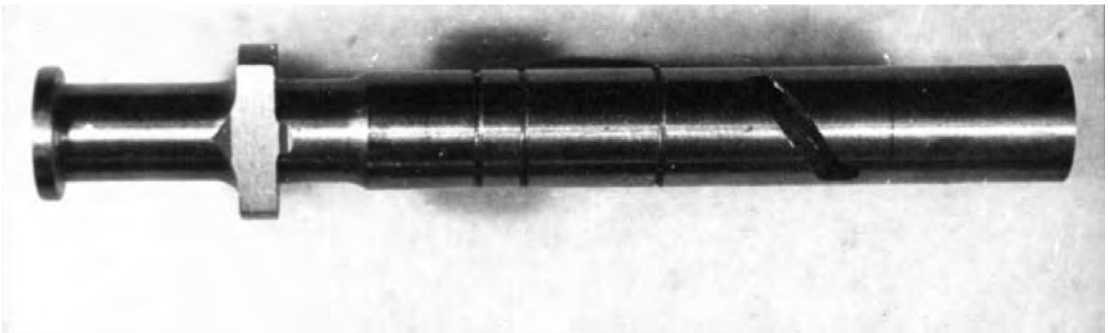


Fig. 9. Photo of the fuel cut off stock with working edges improved with laser transformation hardening.

Laser hardening is very effective as a cutting tool wear resistance increasing technology. It had been proved by many research that almost any type of cutting tool after laser hardening is increasing its long life up to 2–5 times. In some cases there had been observed the wear resistance increase even by factor 10–15 (for example, long broaches of large diameters). Good results had been achieved as well at hardening punches, working elements of blanking dies, etc.

The positive effect of laser hardening may be significantly increased by its combination with other techniques [9].

Laser plastic deformation hardening (LPDH) combines in one process the laser hardening and the thermo-plastic deformation hardening. This provides the possibility to get guaranteed compressed stresses favorable for increasing the fatique strength and wear resistance.

Laser ultra-sonic hardening (LUSH) combines laser irradiation with vibration hardening at ultra-sonic frequencies. Besides the increase in micro hardness the surface topography improvement is achieved as well.

At laser hardening in liquid nitrogen (LHLN) the heat removal from irradiated zone is improved and conditions for better surface alloying with nitrogen are created thus increasing the wear resistance of the treated material.

Gas-powder laser cladding with electro-magnetic agitation (GPLCEMA) includes the action of CO_2 laser radiation, electric arc and variable magnetic field on material. Such combination decreases the tendency to cracks formation, brings positive changes in cladded layers stress state and causes the increase in coating wear resistance.

Laser welding

Laser welding becomes increasingly popular in automotive and aerospace industries. Besides quite known laser steel sheet welding there are some specific applications which are not widespread but still may save a lot of labor and manufacturing time. One of such examples is fuel nozzle (mentioned earlier) restoration. Nozzle itself is quite complicated unit which manufacturing cycle consists of many operations consuming labor, energy and time. The main reason of nozzle wear is hole diameter loss due to fuel burning and deposition of burning products. So to give the nozzle second life is to reweld the worn off holes and to drill the new one. Laser welding is done using the filler stainless steel wire with pulsed Nd:YAG laser. At fig.10 the cross section of rewelded hole and the general view of the restored nozzle are shown.

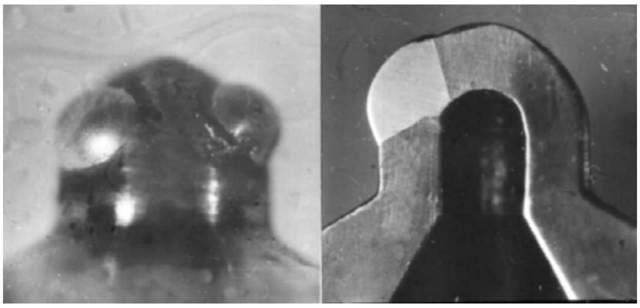


Fig. 10. Appearance and cross-section of welded nozzle apertures for the diesel engine (tested at pressure 280 bar).

In manufacturing of some units for electrotechnical devices used in automotive and aerospace industries there is the necessity to achieve stable joints of transformer steel slices packages for micro electric motors and small transformers. Laser welding is proposed as alternative to mechanical joints or to sintering as the innovating technology providing high quality, productivity, ecology safety and noncontact processing. Laser welding is performed with pulsed Nd:YAG laser in conditions when linear beam scanning is added to the main movement of the beam at unit processing. This additional scanning conducts to lowering temperature of a processed surface and to growth of a life time of a bath of a melt thus improving the weld quality [10].

One of the ways to increase the efficiency of laser welding is hybrid technology based on combination of laser beam and electric arc [11] or plasma interaction with material (fig. 11). Such combination leads to welding process stabilization, to the thermal efficiency increase, to the welding speed increase (up to 2–3 time in comparison with usual plasma powder cladding) and to heat affected zone decrease.

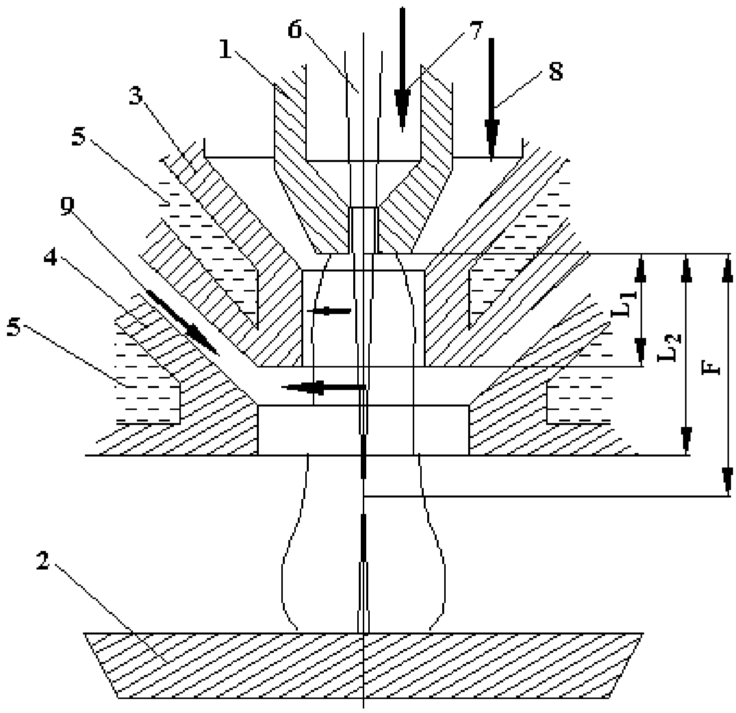


Fig. 11. Scheme of a laser-arc plasmatron:
1 – tube cathode; 2 – surface under processing; 3 – plasma forming nozzle; 4 – powder additive; 5 – cooling water; 6 – focused beam of the CO2 – laser; 7,8 plasma forming gas (argon); 9 – flow of the powder transporting gas (argon).

For the moment the most wide spread type of laser for welding is still CO2 laser, but Nd:YAG laser is already competing successfully with it and slab and diode lasers being considered as the very prospective and highly efficient types of advanced lasers.

Laser marking and engraving

There is a wide field of application for laser marking and engraving in automotive and aerospace industry. The technology of this processing is very versatile and universal and doesn't need special marking or engraving tools. Other very important advantages are very high productivity (speed of forming signs), great variety of signs appearance depending on material and working conditions, possibility to realize unusual design and to perform unique marking operations.

One of such unique application is engraving inside the transparent for laser beam material without its damage (fig. 12).

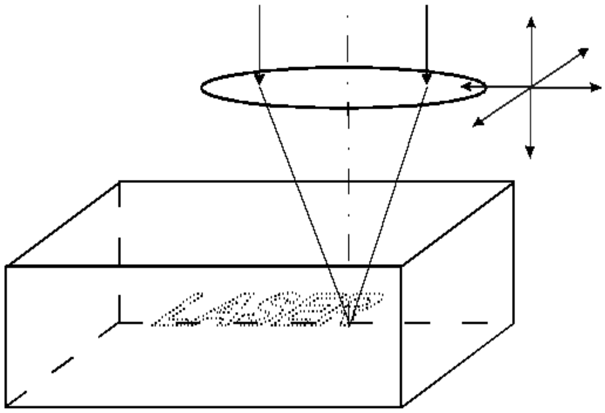


Fig. 12. Laser marking inside the transparent for laser radiation material.

Laser intensification of mechanical cutting

There had been developed few methods of mechanical material cutting assisted with laser radiation. Such methods are of interest for automotive and aerospace industries because they use many advanced materials with new properties which is usually difficult or impossible to machine with conventional methods. So laser is used now to preheat the local zone of the material before removing it with cutting edge tool. In such a way it is possible to decrease significantly the cutting forces. In some cases it is possible to use focused laser beam to initiate the metal chip crush (especially at drilling deep holes).

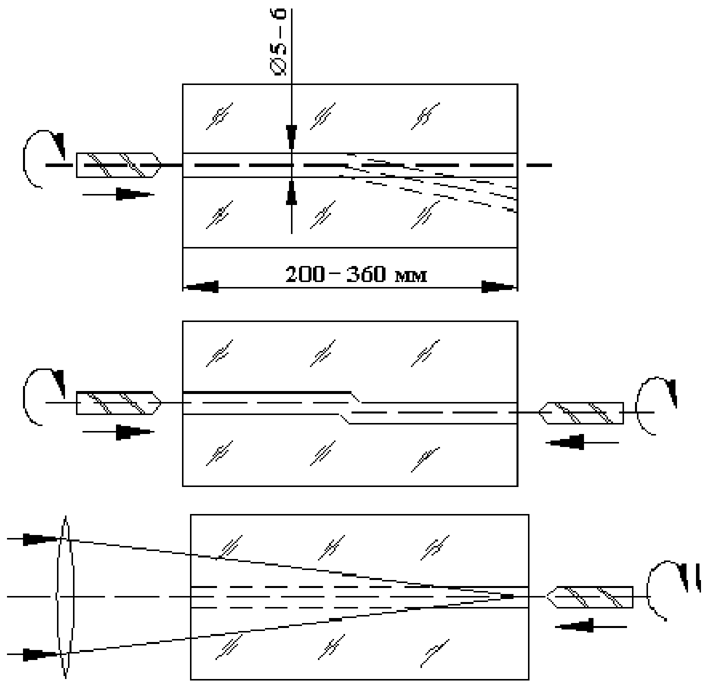


Fig. 13. Three different approaches to get straight line deep hole of small diameter inside the transparent for laser radiation material.

Quite a unique application is drilling long holes of small diameters in a very hard transparent for laser beam material (some types of glass). Traditional drilling with diamond drill of small diameter doesn't provide the straight line ready hole, because long drill isn't rigid enough (fig. 13). So the partial solution of the problem may be the drilling of the hole from different side of the component with more rigid shorter drills. But still sometimes the deviation af axis of both holes may occur. Laser assisted mechanical drilling with one long drill may solve the problem and guarantee the straightliness of the machined hole. In this case laser beam is focused through the bulk of the transparent material just near the tip of the drill. Due to the local destruction of the material in the focal point the drill is easily enters the material. Gradually moving the focal point along the axis it is possible to guarantee the drill movement along the axis without any deviations.

The described technology besides the possibility to get precise straight line deep holes of small diameters provides as well the significant increase in diamond drills durability.

Another good combination of laser assisted mechanical machining is laser dressing of diamond grinding wheels. In contrast to traditional mechanical dressing with diamond pencil which leads to large losses of diamond the laser dressing is very economical technique and prolongs the wheel life significantly. Machining productivity (laser dressing time) practically depends only on wheel diameter and laser pulse frequency (fig. 14). Laser irradiation removes mainly the matrix material (bundle) and grinded material, stored between diamond grains.

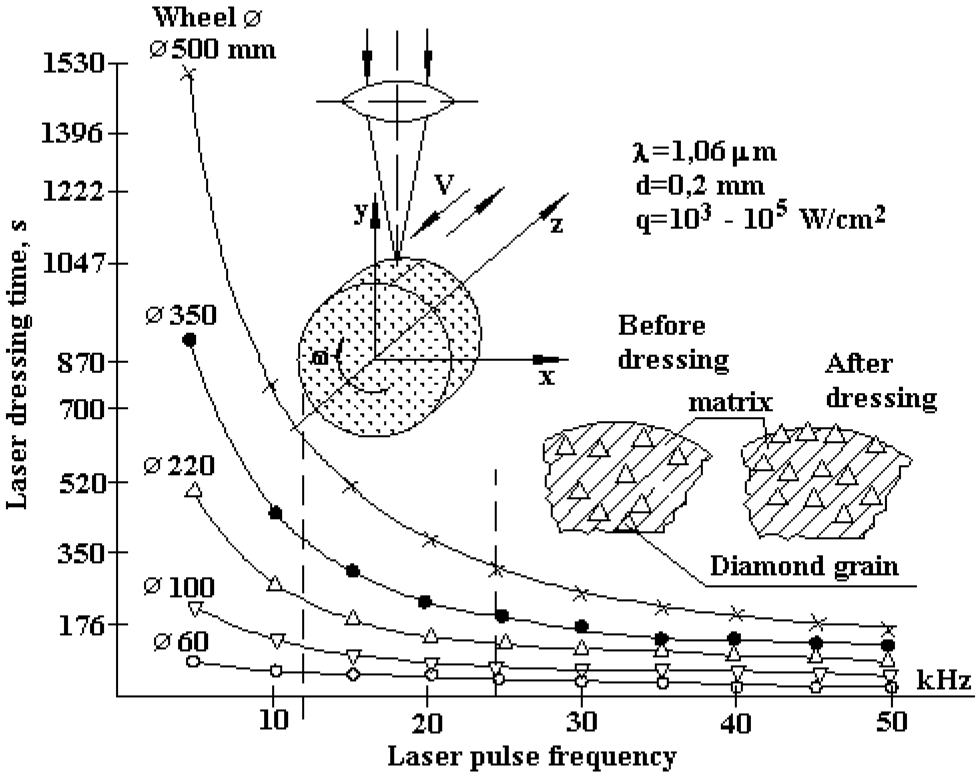


Fig. 14. Scheme of diamond wheel dressing with laser beam.

There are many other combinations of laser technology with traditional mechanical machining as well as with nonconventional methods of material processing. Their implementation into the automotive and aerospace industry will bring better opportunities for manufacturers in their fight with competitors in new conditions of globalize economy.

Conclusions

1. Laser technology provides large variety of manufacturing techniques with wide opportunities to increase the working parameters of manufactured products.

2. Automotive and aerospace industries may benefit a great deal widely implementing advanced technology based on laser radiation use.

3. Industrial laser application are developing fast and there many unique and highly efficient technical solutions to come in the nearest feature

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Summary

For the moment the numerous laser technology applications had been developed and implemented into different fields of industry the automotive and aerospace industries being among the first because of their most expansive, dynamic and fast accepting innovations nature. The applications of laser hole drilling, material cutting, welding, product marking and engraving as well as some mechanical material machining intensified with laser beam are discussed. The possibilities to increase the processing productivity and to imrove the product quality are demonstrated As invited paper this material had been presented at the International Conference “Global Automotive Laser Applications” in the framework of “International School of Quantum Electronics” held at Erice-Sicily (Italy) on 1–7 August 2001 and is given here with some modification.