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Laser cutting. Progress in equipment

Abstract: The article presents the current development and technical possibilities of modern laser cutters, as well as describes today's systems incorporating CO_2 molecular lasers, disc lasers and fibre lasers. The study also analyses the basic equipment and technological aspects related to cutting by means of laser cutters.

Keywords: Laser cutting technology, disc laser, fibre laser

Introduction

Laser cutting continues to be a dominant area of technological laser applications. In percentage terms, as regards industrial applications, cutting significantly outstrips other laser-based technologies, such as welding, overlay welding, surface heat treatment and others. This technology is also expected to remain dominant in the near future. Market analysts predict that one of the regions where laser cutting applications will enjoy a continuous growth is, among others, Central and Eastern Europe [1].

Presently, laser cutting has an established position primarily as a method offering precise cutting of materials of thicknesses below 20 mm. This technology is used mainly for cutting basic structural materials, i.e. steels, aluminium alloys, titanium alloys etc. In most cases, laser cutting, if supported by properly adjusted process parameters, does not need to be followed by additional processing of the cut surface. Cut-out elements can be welded using precise high-power technologies (e.g. electron beam welding or laser welding), assembled mechanically or directly subjected to varnishing, protective coating etc. In terms of thin sheets, laser cutting successfully competes with shearing, hole punching, press cutting and plasma cutting. As regards these applications, the main advantage of laser cutting is the minimum heat affected zone, high quality cut surface, low unitary manufacturing cost and flexibility while changing the profile of production (no need for changing cutting tools). For this reason, laser cutting is widely used for contour cutting of elements of various shapes in conditions of a frequently changing production profile and shapes and type dimensions of elements produced. The examples of laser cutting applications can be counted in the thousands and include, among others, the production of panels, covers, housings, doors, saws, knives and cam mechanisms but also cutting holes in space-shaped, through press forming or spinning, elements of cabins, housings, car bodies etc. [2].

The dominance of laser cutting among other laser technologies is based on the continuous development and improvement of modern laser cutters – machines which incorporate the most advanced achievements as to the design of laser radiation generators, numerical control systems, drives and CAD/CAM software.

Laser types presently used in laser cutters are still dominated by CO_2 lasers, the designs of which are based on generators with a fast longitudinal flow or SLAB lasers, emitting beams of high power and characterised by good transmission and focusing parameters. Recent advances

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in the development of laser radiation generators have led to the increasingly frequent applications of the latest generation of lasers, i.e. disc and fibre ones, in laser cutting machines. Applying such lasers has opened new areas of possible laser cutting applications and caused changes (mostly by simplifying) to the designs of presently manufactured laser cutters. Today the majority of global laser cutter producers offer machines utilising disc or fibre lasers. This article outlines the development and designs of modern laser cutters.

Laser cutters with CO_2 molecular lasers

Due to good absorption of radiation having a wavelength of 10.6 μm and the possibility of precise beam focusing, cutters provided with CO_2 lasers can be used for precise cutting of steel, aluminium or titanium. A radiation beam emitted by CO_2 lasers is also well absorbed by some non-metallic substances such as wood, leather, plastics, paper and fabrics and therefore can be used for cutting such materials as well. CO2 lasers can also be used for cutting sintered elements, textiles and wood.

Depending on their intended application laser cutters are usually provided with CO_2 lasers of power up to several kW. The market offers a whole range of radiation generators (being the outcome of long-lasting improvement and development) for such laser types. These industrially successful lasers having designs based on a longitudinal flow and HF or DC excitation are still used in the production 2D cutters for cutting flat elements, 3D cutters for spatial cutting of elements and specialist machines for cutting only pipes and closed shapes.

The basic difficulty related to the design of cutting machines equipped with w CO_2 lasers, particularly with multiaxial ones (3D), lies in radiation transmission systems. Due to excessive losses, the radiation wavelength of these lasers does not allow effective fibre optic transmission. In most CO_2 laser cutters a laser beam is transmitted from a resonator to the place of processing by so-called “flying optics” systems and an element subject to processing remains motionless (Fig. 1 and 2). Such systems usually contain a set of many (often between ten and twenty) mirrors moving on precise covered guides while a material being cut does not move. The mirror slide systems of older design laser cutters are provided with conventional electric motors and systems of mechanical gears, whereas the latest solutions are equipped with linear drives. Such drives (Fig. 3, 6) make it possible to move mirror guides and cutting heads very fast without the necessity of using gears converting rotary motion to translational motion. The accuracy of positioning in such systems is significantly higher than in conventional drives because all the elements of a conventional drive technology have some backlashes eventually leading to inaccuracy. The application of linear drives in the latest models of laser cutters has significantly improved the efficiency and precision of cutting, particularly of thin sheets. The velocity of the simultaneous positioning of axes in such machines offered on the market may reach 140 m/min at very high acceleration rates [4, 5].

The basic kinematic schemes used in the present designs of cutters for processing flat and spatial elements are presented in Figure 2. Present-day cutters featuring CO_2 lasers are presented in Figures 4-8.

Laser cutters with solid-state lasers

Disc and fibre lasers are modern generations of solid-state lasers. In disc lasers, the radiation emitting active element is a thin ytterbium doped YAG crystal disc (Yb:YAG). In high-power fibre lasers the active elements is a special type of optical fibre (glass fibre) Yb:Glass [4, 9]. Both laser types are excited optically by means of laser diode packages. The disc laser radiation wavelength is 1030 nm, and that of fibre lasers amounts to 1070 nm. These lasers emit a radiation beam with an approximately 10 times

Fig. 1. Laser cutter with a CO_2 laser and a "flying optics" system [6]

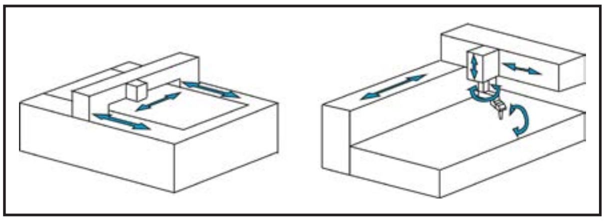

Fig. 2. Popular kinematic schemes of machines with CO_2 lasers and "flying optics" systems

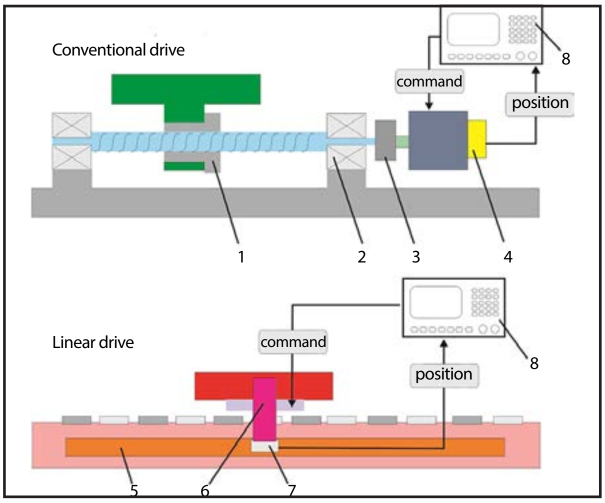

Fig. 3. Schemes of linear drives and conventional drives used in laser cutters: 1: a drive unit, 2: bearings, 3: a clutch, 4: an encoder, 5: a linear scale, 6: a linear drive unit, 7: a scanner head, 8: a CNC control system

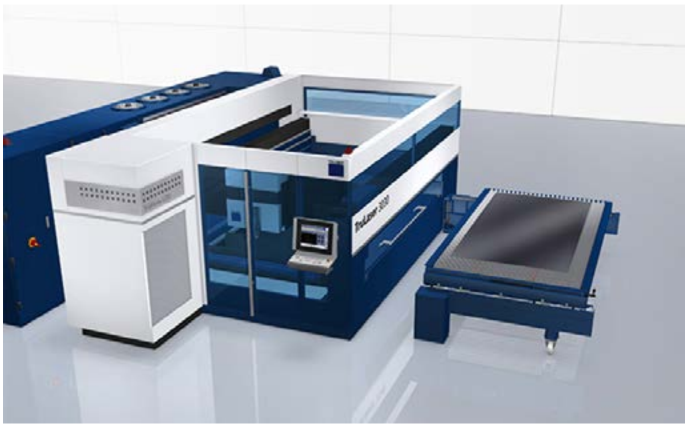

Fig. 4. 2D laser cutter TruLaser 3030 Lean Edition manufactured by Trumpf [4]

Fig. 5. 2D laser cutter series LC-F1 NT manufactured by Amada, provided with linear drives [6]

Fig. 6. Linear drive placed on the side (good protection against impurities) of Amada FOL 3015 NT laser cutter [6]

Fig. 7. BySprint 3015 2D laser cutter by Bystronics. The maximum velocity of simultaneous positioning of axes - 140 m/min; the maximum axis acceleration - 12 m/s^2 [5]

Fig. 8. TruLaser Cell 7040 processing centre for cutting spatial elements [4]

shorter wavelength than CO_2 molecular lasers. Radiation of this wavelength can be relatively easily entered into and transmitted via optical fibres. These lasers are characterised by high efficiency (of approximately 25%), a compact resonator design and good beam quality (a low BPP coefficient). It is possible to focus such a beam more intensively and, as a result, obtain greater radiation power density. Laser radiation with a wavelength of approximately 1000 nm is much better absorbed by copper, gold, silver and their alloys than CO_2 laser radiation. The advantages enumerated above have led to increasingly wide application of these lasers in cutting processes. Laser cutters usually utilise lasers of power up to several kW.

The most important feature affecting the design of cutting machines in which radiation is generated by disc and fibre lasers is the possibility of transmitting a beam by means of optical fibres. In this case the transport of a beam does not require complicated systems of drives and guides moving mirrors. After leaving a laser, a beam is transported to a focusing head in a flexible optical fibre (Fig. 9). Similarly as in the latest CO_2 laser designs, a cutting head coupled with an optical fibre is moved using linear drives. Disc and fibre lasers are often fixed in the main housing of a machine (Fig. 9 and 10), which decreases the requirements related to mounting spaces by approximately 20% and provides easier access to service areas. The examples of modern cutters provided with disc and fibre lasers are presented in Figures 11 and 12.

Solid-state laser designs are usually provided with several optical outputs, which make it possible for one source to be used on several stations (Fig. 13). Such lasers can operate in so-called Laser Net-work systems, i.e. systems composed of several laser processing stations and one radiation source. Equipment manufacturers also offer cutting machines with one source and two working heads (Fig. 14), which enables a further increase in process efficiency.

In fibre optic transmission, the diameter of a beam in a focus depends in direct proportion on the diameters of an optical fibre and the focal length of a focusing lens and in inverse proportion on the focal length of a collimator lens. The easy change of an optical fibre or directing a beam to an optical fibre having a different diameter makes it possible to precisely adjust a focus spot size and power density optimum for a given cutting process or another type of laser processing.

The automatic deactivation of a resonator during machine standstill and advanced highly efficient cooling systems used in modern laser cutters additionally decrease power consumption if compared with older designs. Table 1 presents a comparison of the most important advantages of various types of lasers applied in cutting processes.

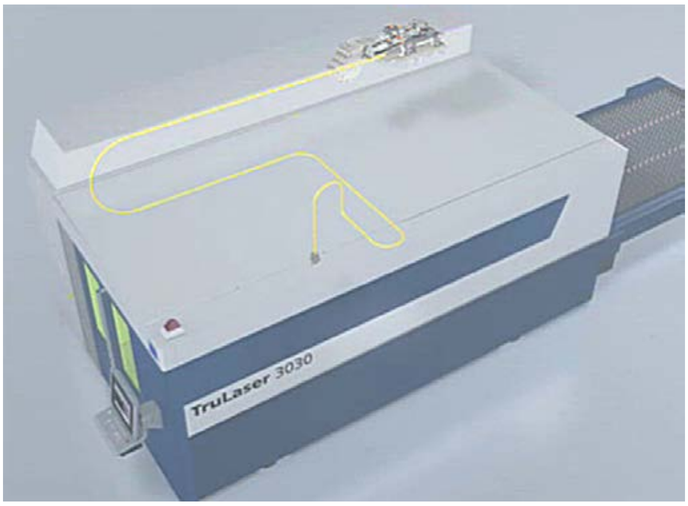

Fig. 9. Scheme of fibre optic radiation transmission in a modern laser cutter [4]

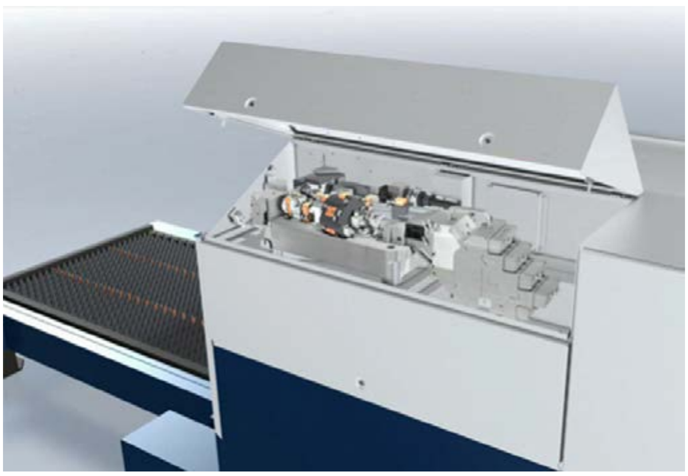

Fig. 10. Disc laser in the main housing of a laser cutter [4]

Fig. 11. Laser cutter Optiplex 3015 fiber with a fibre laser by Mazak Optonics [7]

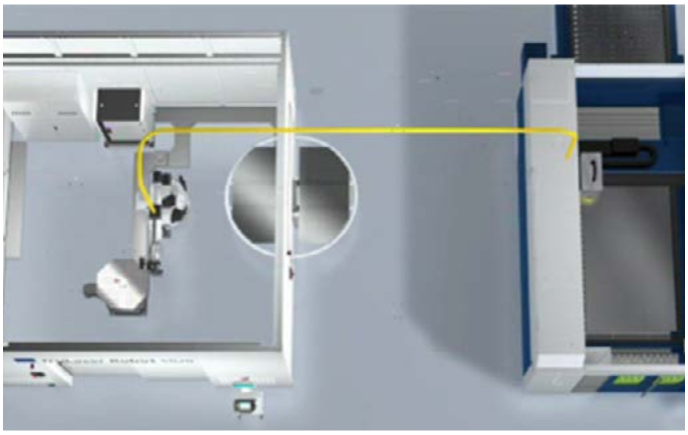

Fig. 13. Possibility of using a laser with fibre optic transmission for operation on two cutting stations [4]

Fig. 12. Laser cutter TruLaser 3030 fiber by Trumpf with a disc laser and fibre optic radiation transmission [4]

Fig. 14. Laser cutter TruLaser 7040 fiber with two cutting heads [4]

Table 1. Comparison of laser advantages in cutting applications [4]

	CO_2 laser	Solid-state laser
Materials and thicknesses		
Unalloyed steels (O_2)*	very good for all thicknesses	very good for all thicknesses
Stainless steels, unalloyed steels (N_2)	very good for cutting thick plates	very good for cutting thin sheets
Aluminium (N_2)	very good for all thicknesses	very good for cutting thin sheets (particularly)
Non-ferrous metals (O_2/N_2)	Not useful	very good for cutting non-ferrous materials
Versatility		
Laser power	Up to 8 kW	Up to 6 kW
Possibility of operation in LaserNetwork systems	No	Yes
Tolerance to sheet thickness deviations	++	++
Costs		
Power consumption	+	++
Consumable materials	++	++
Spare parts costs	++	++

Assessment result: "+" – good, "++" – very good
*O_2 – cutting with the use of oxygen; N_2 – cutting with the use of nitrogen

Optimisation of a cutting process using special designs and software modules

The achievable cutting quality and process efficiency are affected not only by the very design of a laser cutter and the type of a laser used. Other factors of great importance include the adjustment and optimisation of the basic process parameters as well as the use of special technological procedures connected with cutting process control. Most modern laser cutters are provided with a number of special design and software modules for the maximum optimisation and increase in cutting process efficiency and quality.

The most important factors decisive for the efficiency and quality of cutting include

– laser radiation beam parameters, i.e. power, frequency, mode, power stability, cross-section, divergence and polarisation;
– parameters of a radiation beam transmission system, i.e. the type of an optical fibre or a "flying optics" system, the properties of focusing elements, the possibilities of positioning a beam in relation to a nozzle and the surface of a material, the diameter of a nozzle and the position of a beam focus;
– control system and manipulator parameters, i.e. the range of a slide velocity and its stability, the accuracy of working head movements;
– working gas parameters and their precise adjustment possibilities, i.e. a type, purity, pressure and flow rate;
– material parameters, i.e. the thickness of an element, the type of a material, the condition of material surface and the geometry of an element cut out.

Variable parameters available for the operator, i.e. the parameters, by means of which it is possible to adjust the optimum combination for a given cutting process include a cutting velocity, the focusing power of a focusing system, the position of a focus in relation to the surface of a material being cut, the type, pressure and flow rate of working gas, the geometry of a working head nozzle and its position in relation to the surface of a material being cut. The quality of cutting is also affected by phenomena accompanying the start of a cutting process, particularly when taking place inside a sheet (so-called punching), and by the manner of positioning a tool over a contour.

All the enumerated parameters are selected for the type (the whole or part) of a contour to be cut out. The parameters of punching, positioning a tool over a contour and cutting which can ensure proper cutting of a hole having a diameter of, e.g. several millimetres differ dramatically from the parameters of cutting a large-size rectilinear contour. In the first case the rate of cutting amounts to, e.g. 0.1 m/min, in the other case, the rate may be as many as a few metres per minute. Cutting sharp corners requires special techniques of positioning a tool onto a contour making it possible to minimise roundings, e.g. so-called looping – positioning a tool over a contour over a loop trajectory. In the latest solution the place of punching is sprayed with water from holes in a cutting nozzle. This is done in order to reduce the hole and the area of punching. As a result it is possible to arrange elements to be cut even closer to each other.

During cutting large-size sheets out of which one can cut, for instance, several hundred elements having various contour geometry, it is necessary to use many different sets of parameters of punching, positioning a tool over a contour and cutting. The positioning systems and control systems of presently used cutters based on CO_2 lasers and solid-state lasers ensure proper repeatability, stability and real-time reactions necessary to carry out such cutting processes. The control systems of the most advanced machines can determine the position of the edge of a sheet on a table and carry out cutting with a common edge.

Properly selected parameters of cutting individual fragments of a contour (e.g. the length of the section of positioning a tool over a contour) are taken into consideration during planning the optimum cutting of a sheet. Also the sequence of cutting out individual elements and an access route to successive elements of a cutting contour require to be optimised. The optimum cutting is programmed using modern technologically-oriented computer programming systems integrated with cutters.

Cutting technologies are also optimised for the efficiency and flexibility of the whole process as well as for material economy. Today's cutters are designed for easy integration with systems of automatic loading and unloading of sheets, high-bay warehouses, systems of slide tables or even whole automated production lines. The efficiency and flexibility of cutting processes can also be improved by using "micro-joint" or "micro-weld" techniques preventing already cut-out elements from falling out of sheets. The use of both these techniques can facilitate loading, unloading and transport of individual elements or whole sheets, thus increasing the efficiency of the whole process.

The designs of modern cutters incorporate modules and systems aimed at the minimisation of the operator's participation in a cutting process. In modern machines, the exchange of worn-out cutting nozzles is automatic and involves the use of special pallets with new nozzles or with nozzles of various diameters which can be changed depending on the manner of cutting.

Modern cutters based on processes in which nitrogen is used as working gas allow using very high working gas pressure, i.e. up to 20 bar. By controlling the position of a beam focus it is possible to control plasma in a cutting gap. Such a solution makes it possible to cut 8÷15 mm thick aluminium and 20÷25 mm thick stainless steels at the same time obtaining a high quality cut surface [4].

Fig. 15. Pallet with exchangeable nozzles in a modern cutter produced by Trumpf [4].

Summary

Laser cutters currently offered on the market feature both CO_2 lasers and solid-state lasers. The recent decade has seen significant qualitative changes in the development of laser cutting machines. The designs of machines have changed significantly due to the implementation of linear drives as well as disc and fibre lasers. This has enabled the use of the fibre optic transmission of radiation. The implemented changes have significantly extended the technological possibilities of laser cutters enabling further advances in process efficiency and precision as well as increasing the range of materials which can be cut. The technology of the process utilising all laser types has continued to be enhanced and optimised by improving and introducing special modules in control systems and machinery design. Due to the properties of laser as a heat source supported by progress in machines and technologies, laser cutting remains dominant among material processing laser technologies.

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